MIGAL.CO

WIR SIND AUF DRAHT!



Wire electrodes and welding rods

Welding consumables.

Your key to
perfect welding.

05 Aluminium Page 23

06 Copper Page 55

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08 Nickel Page 101

09 Low alloy Page 107

The company

MIGAL.CO.

We know our wire

MIGAL.CO (formerly MIGWELD) has existed since 1 January 2000, is based in Landau an der Isar and manufactures high-quality filler metals for MIG/MAG and TIG welding.



MIGAL.CO in Landau an der Isar

Robot quality: consistent products

Wire electrodes from MIGAL.CO are distinguished by outstanding wire feeding properties. The reason is a special cleaning and treatment of the surface during production.

The prerequisite for successful welding with industrial robots in high-volume production is a consistent product that guarantees the same arc characteristics from batch to batch.

Our quality assurance begins with the mining of the aluminium ore bauxite. The always identical supply chain from the ore to the wire rod of 9,5 mm diameter yields alloys with a consistently identical fingerprint of trace elements.



Slip-free drawing machine

Slip-free drawing

For drawing the wires we use only slip-free drawing machines of the highest quality: each drawing die has its own speed-controlled drive. Slip is thus reliably avoided, which ensures an optimum surface finish.

The MIGAL.CO quality

Diameter and surface.

Diameter tolerance, surface cleanliness, freedom from twist

According to DIN EN ISO 544, the diameter of a 1,2 mm wire electrode for gas-shielded metal arc welding may deviate from the nominal diameter by +0,01/−0,04 mm. MIGAL.CO keeps it constant within +0,00/−0,02 mm.

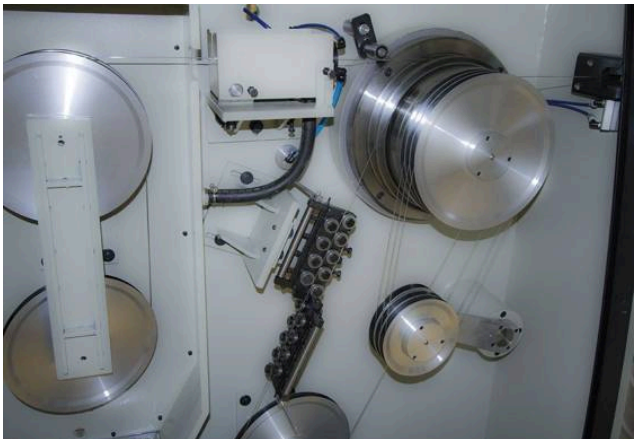
Diameter	Deviation	Cross-section	Deviation
1,21 mm	+0,83 %	1,15 mm²	+1,65 %
1,20 mm	0,00 %	1,13 mm²	0,00 %
1,18 mm	−1,67 %	1,09 mm²	−3,31 %
1,16 mm	−3,33 %	1,06 mm²	−6,48 %

Shaved surface

We clean the surface by a multiple mechanical, metal-cutting process known in the trade as shaving. Unlike chemical cleaning processes, it produces the best possible surface cleanliness: pure metal.

Laser monitoring

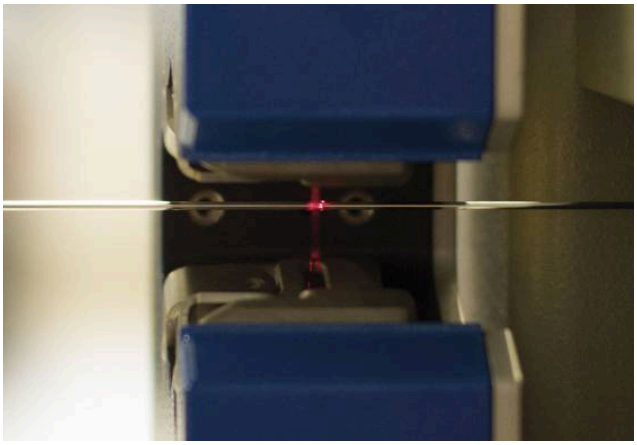
The diameter and ovality of the wire are monitored continuously by laser during production. Deviations trigger warnings or stop the production line.



Drawing machine with adjustment of freedom from twist

MIGAL.CO draws its wires with diamond drawing dies. This limits the greatest possible deviation in wire feed speed to 3,31 %.

In practice this means: with a new wire batch, the arc length correction does not have to be readjusted. This is of great importance for every mechanised or robotic weld.



Diameter monitoring by laser

Twist-free wires

For optimum processing, wire electrodes for MIG/MAG welding must be twist-free. Especially in robotic welding, this ensures a precise position of the wire tip at the TCP (Tool Center Point) and prevents tangles when the wire is drawn from the drum. Our drawing machines have special devices for adjusting the freedom from twist.

Residue analysis.

Precision in surface coating

> Metallically clean aluminium does not slide through the wire feeding system. Every wire therefore needs a lubricant, but only so much that the surface stays clean. We measure how much is actually on the wire.

How a manufacturer of filler metals achieves the compromise between good sliding properties and the greatest possible surface cleanliness is a closely guarded secret. That also applies to MIGAL.CO, although we believe we have solved this particularly well.

In any production, errors can occur that lead to unclean surfaces. Incorrect storage or contaminated wire feeding equipment can likewise soil the wire surface. With aluminium this is of the utmost importance because of the hydrogen problem (see page 43) and in practice often involves considerable difficulties.

We therefore developed our residual analyser. With it we can make concrete statements about the surface cleanliness of filler metals quickly and on site.



Residual analyser SMKY 2, second generation

HOW IT IS MEASURED

25 cm
Wire electrodes are clamped into the device

10 s
is the maximum duration of the adjustable current pulse

250 A
heat the wire to just below its melting point

0–1 mg/m³
Measuring range of the sensor for the smoke produced



User interface: measurement curve and numerical value per sample

What the result tells you

The residues on the surface evaporate, are captured completely by an extraction hood and measured by quantity. The result is displayed as a graph and as a numerical value and can be documented cleanly. On request, several measurements are combined into a mean value.

- Too little lubricant: dry wire, wire feeding faults
- Too much lubricant: pores, spatter and smoke

The analyser is mobile and can be used directly on the user's premises. If problems such as pores occur, a concrete statement on the cleanliness of the wire electrode is available very quickly.

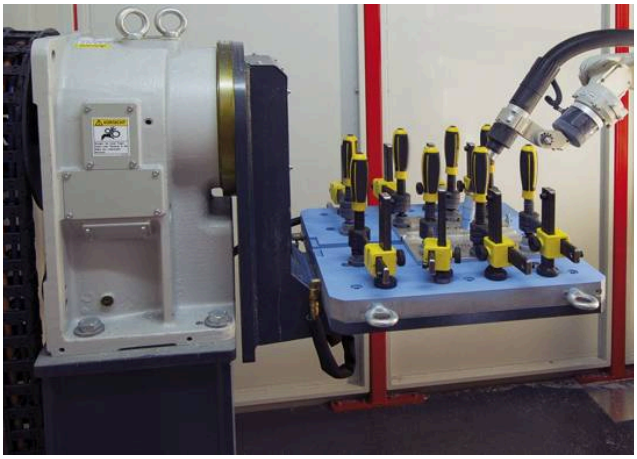
Residual analyser SMKY 2
migal.co/en/products/residual-analyser

Welding test, X-ray and laboratory.

Only a welding test followed by radiographic inspection provides the decisive statement on the quality of a filler metal.

Welding robot and digital X-ray

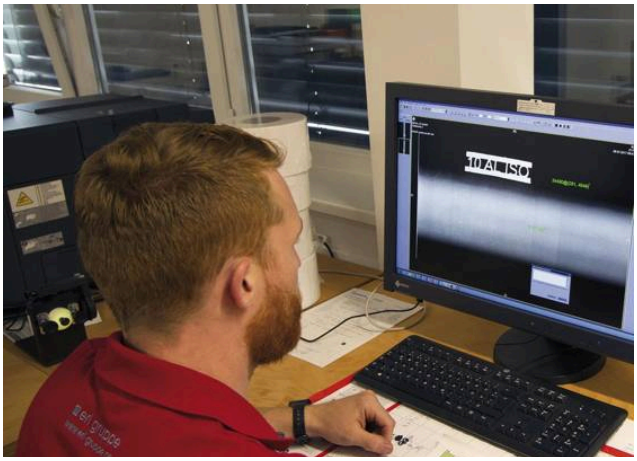
An industrial robot dedicated to this purpose, with statistical process analysis, and a digital X-ray system enable us to verify the processing quality and freedom from pores of our products before they are delivered.



Welding robot



X-ray cabinet



Evaluation of the digital X-ray images

Spectral analysis, tensile test and friction

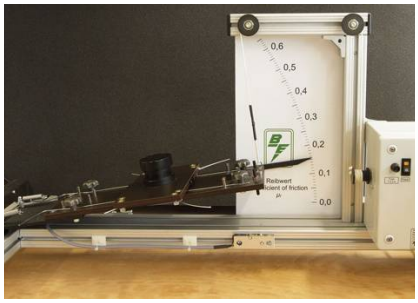
In our laboratory we check the chemical composition of our products at any time, determine the tensile strength, yield strength and elongation of the wires and measure the coefficient of friction of the wire electrodes.



Spark emission spectrometry



Tensile test



Determining the friction coefficient

Vacuum packaging.

Standard for all wire electrodes on spools

Only wires on whose surface condensation has taken place lead to pores in the weld metal. That is why MIGAL.CO is the first manufacturer worldwide to pack all wire electrodes on spools from 0,5 to 40 kg in aluminium composite foil under vacuum.

What research shows

From 2013 to 2016, the Welding and Joining Institute (ISF) of RWTH Aachen University carried out “Investigations into the influence of the material-dependent properties of aluminium wire electrodes on the stability and the welding result in gas-shielded welding processes”.

The clear result: pores in the weld metal are caused only by wires on whose surface condensation has taken place. Condensation due to rapid changes in temperature and humidity occurs during storage and especially during transport, i.e. during a process that may be beyond the control of manufacturer and recipient.

Why foil and vacuum

The plastic packaging commonly used for wire electrodes until now is by no means tight. Under condensation conditions the wire picks up hydrogen, and pores form during welding.

The vacuum packaging reliably protects the wire electrode against hydrogen pick-up, even during storage or transport under condensation conditions. And the user can see at a glance whether the packaging is intact.



B 300 in vacuum packaging



S 300 in vacuum packaging

More on this topic. When condensation forms and how to avoid it is explained on page 45; why even a little hydrogen causes pores, on page 43.

The technology centre

Technology centre.

We supply the solution with the product

> For new arc processes, empirical values are often lacking. There is only one way to find answers for the specific application: trying it out. That is what our technology centre is for.

The arc continues to evolve

Advances in microelectronics have developed the arc as a tool considerably in recent years. New process variants such as high-performance MIG/MAG welding, MIG brazing, flat-wire welding or AC MIG/MAG welding have emerged. At the same time, known processes such as plasma-MIG welding are being rediscovered and new hybrid processes such as laser-MIG welding developed.

These advances can be turned into quality and productivity of the welded joints, which is more important than ever in global competition.

Testing instead of guessing

The boundary conditions and performance data of the new processes have not yet found their way into the literature. Materials, weld types, positions, tolerances and requirements are also too diverse.

In the technology centre we test various arc processes under practical conditions, compare them with one another, and assess and document the results by means of weld tests.

Solutions that work in practice

We develop these solutions within a very short time and on the basis of industrially manufactured products, which can then actually be used in practice.

To be able to offer the full spectrum of destructive and non-destructive materials testing and the latest scientific findings, we have entered into partnerships with universities and institutes.

The internet

Online services.

Test certificates, stock list, metal surcharges and calculators on migal.co

> Our website is linked directly to our ERP system. Customers obtain information online from our databases: quickly, precisely and around the clock.

Test certificates

We supply all filler metals with an inspection certificate to EN 10204 – 3.1. The certificate can be retrieved online at any time, even years later.

Enter the batch number of the filler metal on migal.co and select dimension and spool type in the search results. The certificate appears as a PDF and can be printed or saved. A correct and properly assigned document is thus available at any time.

Stock list

All filler metals currently in stock can be looked up with the exact quantity in kilograms, by alloy, diameter and spool type. The QR code on every data sheet in this catalogue takes you straight there.

Metal surcharges

The metals our filler metals are made of are traded on the international markets and are subject to daily price fluctuations. Our sales prices therefore consist of a base price and a variable surcharge. It is calculated from the changes in the respective metal prices over the previous month.

On request, we will gladly inform you about the basis of calculation.

Please note. The metal surcharges of the month of delivery always apply, not those of the month in which the order was placed. The surcharges are exclusive of value added tax.

Current values: migal.co/service/metallzuschlaege

Calculators and expertise

Material calculator

The right filler metal for every aluminium base material

Dew point calculator

When condensation forms on wire and component

Wire length calculator

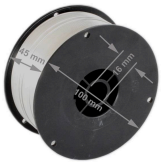
Metres of wire per spool or drum, see also page 20

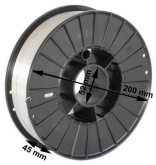
Spools.

Mandrel spools and basket spools

Which spool type is available for which alloy is stated in the respective data sheet under “Dimensions and packaging”.

Aluminium

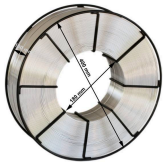

S 100
0,5 kg


S 200
2 kg


S 300
6 kg

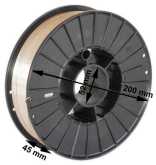

B 300
7 kg


BS 300
7 kg


B 400
18 kg


B 400
40 kg

Copper alloys


S 200
5 kg


S 300
15 kg


B 300
15 kg


BS 300
15 kg

Spool	Aluminium	Copper	Stainless, nickel	Low alloy
S 100	0,5 kg	–	–	–
S 200	2 kg	5 kg	–	–
S 300	6 kg	15 kg	–	–
B 300 / BS 300	7 kg	15 kg	15 kg (BS 300)	18 kg (B 300)
B 400	18 and 40 kg	–	–	–

S, B, BS. S = plastic mandrel spool, B = wire basket spool, BS = basket spool with adapter mount. Aluminium spools are supplied vacuum-packed as standard (page 7). Drums: page 12. Wire lengths per spool and drum: page 20.

Packaging and TIG rods.

Vacuum-packed spools



S 200
vacuum-packed



S 300
vacuum-packed



B 300 / BS 300
vacuum-packed



B 400
vacuum-packed

Cartons



Carton 300
for S 300, B 300, BS 300



Carton 400
for B 400

TIG rods



TIG rods in cartons

TIG rods are 1.000 mm long. We supply aluminium rods in tubes of 2,5 kg or in cartons of 5 or 10 kg, copper rods in cartons of 5 or 10 kg, and stainless, nickel and low-alloy rods in cartons of 5 kg.

All aluminium rods are embossed on one side with MIGAL.CO and the alloy number.



Tube 2,5 kg

Wire from the drum.

Eco drum, Jumbo drum and JumboXL drum

For mechanised and robotic welding tasks: the wire is fed directly from the drum, without the otherwise necessary, expensive and maintenance-intensive decoiling device.



Eco drum

Mainly for alloys of the 1000 and 4000 series and for CuSi3 with 1,0 mm for MIG brazing.

Aluminium	80 kg
Copper-based	200 kg
Diameter	515 mm
Height without hood	800 mm
Height with hood	1.120 mm



Jumbo drum

For all aluminium alloys in the product range, including 1,0 mm diameter and alloys of the 5000 series.

Aluminium	140 kg
Copper-based	200 kg
L × B	600 × 600 mm
Height without hood	900 mm
Height with hood	1.250 mm



JumboXL drum

The largest unit for bulk users of aluminium welding wire.

Aluminium	240 kg
Copper-based	–
Diameter	750 mm
Height without hood	800 mm
Height with hood	1.120 mm

What all drums have in common

- A viewing window shows how much wire is left in the drum.
- After use, the drum is disposed of as waste paper or incinerated.
- Because of the large drum diameter, the wire from Jumbo and JumboXL comes out almost straight and is therefore particularly suitable for laser welding.

Planning the system. How drum, wire feed conduit and robot are arranged so that the wire runs without an auxiliary drive is shown on page 13.

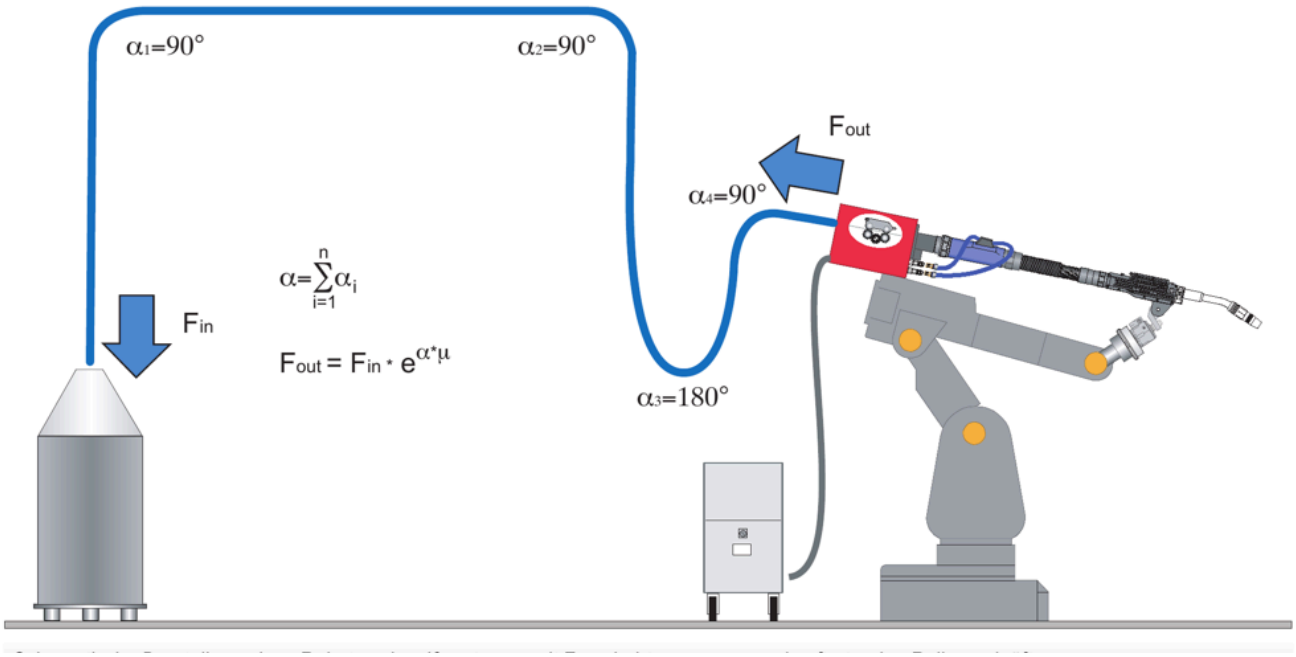
Drum hoods, drum connectors and the universal drum trolleys UFTW1 and UFTW2 can be found in the Wire transport catalogue.

Current status
migal.co/en/products

System layout.

Planning wire feeding from the drum

Trouble-free use of wire drums requires a great deal of experience. The spatial layout of the welding installation already determines whether the wire runs easily.



Robotic welding system with wire supply from the drum and the friction forces occurring (schematic)

Every bend costs force

The force the drive has to apply grows with the sum of all deflection angles between drum and torch:

$$F_{out} = F_{in} \cdot e^{\alpha \cdot \mu} \quad \text{with} \quad \alpha = \Sigma\ \alpha_i$$

In the example, four bends add up to 450°. Few, wide bends and a low coefficient of friction μ keep the feeding force small.

We plan with you. We will gladly support you as early as the system planning stage – just contact us.

For longer feeding distances from the drum to the wire feeder we recommend our Rolliner. You will find it and further accessories for wire drums (drum hoods, wire end detectors, wire feed conduits, connectors, transport equipment) in the Wire feeding catalogue.

Chemical composition.

Aluminium alloys

Values in %. Single values are maximum values. `0,00–0,00` marks the alloying elements with a specified range.

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Be	Ti	Zr	B	others each	others total	Al	Page
MA-1070	0,20	0,25	0,04	0,03	0,03		0,04	0,0003	0,03			0,03		≥99,70	24
MA-1450	0,25	0,40	0,05	0,05	0,05		0,07	0,0003	0,10–0,20			0,03		≥99,50	25
MA-2319	0,20	0,30	5,80–6,80	0,20–0,40	0,02		0,10	0,0003	0,10–0,20	0,10–0,25		0,05	0,15	Balance	26
MA-4018	6,50–7,50	0,20	0,05	0,10	0,50–0,80		0,10	0,0003	0,10–0,20			0,05	0,15	Balance	27
MA-4020	2,50–3,50	0,20	0,03	0,80–1,20	0,01			0,0003	0,005	0,01		0,02	0,10	Balance	28
MA-4043	4,50–6,00	0,60	0,30	0,15	0,20		0,10	0,0003	0,15			0,05	0,15	Balance	29
MA-4046	9,00–11,00	0,50	0,03	0,40	0,20–0,50		0,10	0,0003	0,15			0,05	0,15	Balance	30
MA-4047	11,00–13,00	0,60	0,30	0,15	0,10		0,20	0,0003	0,15			0,05	0,15	Balance	31
MA-5087	0,25	0,40	0,10	0,70–1,10	4,50–5,20	0,05–0,25	0,25	0,0003	0,15	0,10–0,20		0,05	0,15	Balance	32
MA-5183	0,40	0,40	0,10	0,50–1,00	4,30–5,20	0,05–0,25	0,25	0,0003	0,15			0,05	0,15	Balance	33
MA-5356	0,25	0,40	0,10	0,05–0,20	4,50–5,50	0,05–0,20	0,10	0,0003	0,06–0,20			0,05	0,15	Balance	34
MA-5554	0,25	0,40	0,10	0,50–1,00	2,40–3,00	0,05–0,20	0,25	0,0003	0,05–0,20			0,05	0,15	Balance	35
MA-5556	0,25	0,40	0,10	0,60–1,00	5,00–5,50	0,05–0,20	0,20	0,0003	0,05–0,20			0,05	0,15	Balance	36
MA-5754	0,40	0,40	0,10	0,50	2,60–3,60	0,30	0,20	0,0003	0,15			0,05	0,15	Balance	37
MA-6063	0,20–0,60	0,35	0,10	0,10	0,45–0,90	0,10	0,10	0,0003	0,20–0,30		0,04–0,06	0,05	0,15	Balance	38

Grouping of filler metals

Typ	MIGAL.CO and chemical designation		Remarks
Typ 1	MA-1450	Al99,5Ti	Ti reduces the formation of solidification cracks in the weld metal through grain refinement.
	MA-1070	Al99,7	
Typ 4	MA-4018	AlSi7Mg	These filler metals turn dark grey during anodising or through atmospheric exposure, the more so the higher the Si content. They are not a good colour match for base materials made of wrought alloys. They are used to prevent solidification cracking in joints with high dilution and rigid restraint.
	MA-4020	AlSi3Mn1	
	MA-4043	AlSi5(A)	
	MA-4046	AlSi10Mg	
	MA-4047	AlSi12(A)	
Typ 5	MA-5754	AlMg3	If corrosion resistance and colour match are decisive, the Mg content of the filler metal should equal that of the base material. If high yield strength and ultimate strength of the weld metal are decisive, the Mg content should be 4,5 % to 5 %. Cr and Zr reduce the susceptibility to solidification cracking, Zr reduces the risk of hot cracking.
	MA-5554	AlMg2,7Mn	
	MA-5556	AlMg5Mn1(A)	
	MA-5183	AlMg4,5Mn0,7(A)	
	MA-5087	AlMg4,5MnZr(A)	
	MA-5356	AlMg5Cr(A)	

The type numbers 1, 4 and 5 correspond to the first digit of the alloy designation. Extract from DIN EN 1011-4. Safety data sheets are available on migal.co.

Selection of filler metals.

Aluminium alloys, to DIN EN 1011-4

The digits denote the filler metal types according to the grouping on page 14. Per box: first line optimum mechanical properties, second line optimum corrosion resistance, third line optimum weldability. For individual base materials: material calculator on migal.co.

Base material A	Al	AlMn	AlMg < 1 %	AlMg 3 %	AlMg 5 %	AlMgSi	AlZnMg	AlSiCu < 1 %	AlSiMg	AlSiCu	AlCu
Al	4 1 4										
AlMn	4 or 5 1 4	4 – 4									
AlMg < 1 % [a]	4 or 5 1 4	4 4 4	4 4 4								
AlMg 3 %	4 or 5 5 [d] 4 or 5	5 5 [d] 4	5 5 [d] 4	5 5 [d] 5							
AlMg 5 % [b]	5 5 5	5 5 5	5 5 5	5 5 5	5 5 5						
AlMgSi [c]	4 or 5 5 4	4 or 5 5 4	4 or 5 5 4	5 5 4	5 5 4	5 or 4 5 4					
AlZnMg	5 5 5	5 5 5	5 5 5	5 5 5	5 5 5	5 5 5	5 5 5				
AlSiCu < 1 % [e, f]	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4			
AlSiMg [e]	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4		
AlSiCu [e, f]	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	
AlCu [c]	g	g	g	g	g	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	g g 4
Base material B	Al	AlMn	AlMg < 1 %	AlMg 3 %	AlMg 5 %	AlMgSi	AlZnMg	AlSiCu < 1 %	AlSiMg	AlSiCu	AlCu

Note 1: If the base materials contain about ≥ 2 % Mg and are welded with filler metals of type AlSi5 or AlSi12 (or contain ≥ 2 % Si and are welded with AlMg5 types), sufficient Mg_2Si precipitates can form at the fusion line to embrittle the joint. These combinations are not recommended for components under dynamic or impact loading. If the combination cannot be avoided, filler metals of type AlMg5 or AlSi5 may be used.

Note 2: The base materials are listed by their chemical composition, without reference to wrought or cast materials.

[a] When welded without filler metal, these alloys are susceptible to solidification cracking. This can be prevented by rigid clamping or by an Mg content of more than 3 % in the weld pool.

[b] Under certain environmental conditions, e.g. at temperatures ≥ 65 °C, alloys with more than 3 % Mg may be susceptible to intergranular corrosion and/or stress corrosion cracking. The susceptibility increases with rising Mg content and/or in the work-hardened condition. The effect of weld metal dilution should be taken into account.

[c] These alloys are not recommended for welding without filler metal, as they are susceptible to cracking.

[d] The resistance of type 5 to intergranular corrosion and stress corrosion cracking increases if the Mg content does not exceed approx. 3 %. Under service conditions that can cause such corrosion, the Mg content of the weld metal should be similar to that of the base material and not significantly higher.

[e] The silicon content of the filler metal should match that of the cast alloy of the base material as closely as possible.

[f] Die-cast alloys are not weldable because of their gas content.

[g] Not recommended, not suitable for the base material.

Chemical composition.

Copper alloys

Values in %. Single values are maximum values. `0,00–0,00` marks the alloying elements with a specified range.

Alloy	Al	Si	Mn	Ni	Zn	Sn	Pb	Ti	Fe	P	As	Others total	Cu	Page
ML CuAl8	6,00–8,50	0,20	0,50		0,20		0,02					0,40	Balance	56
ML CuAl8Ni2	7,00–9,50	0,20	0,50–2,50	0,50–3,00	0,20		0,02		0,50–2,50			0,40	Balance	57
ML CuAl8Ni6	8,50–9,50	0,10	0,60–3,50	4,00–5,50	0,10		0,02		3,00–5,00			0,50	Balance	58
ML CuAl9Fe	8,50–11,00	0,10			0,02		0,02		1,50			0,50	Balance	59
ML CuMn13Al7	7,00–8,50	0,10	11,00–14,00	1,50–3,00	0,15		0,02		2,00–4,00			0,50	Balance	60
ML CuNi10Fe	0,03	0,20	0,50–1,50	9,00–11,00			0,02	0,20–0,50	0,50–2,00	0,007		0,40	Balance	61
ML CuNi30Fe		0,20	0,50–1,50	29,0–32,0			0,02	0,20–0,50	0,40–1,00	0,02		0,50	Balance	62
ML CuSi28L	0,02	2,80–3,00	0,75–0,95	0,05	0,10	0,05	0,01		0,10	0,05		0,50	Balance	63
ML CuSi3	0,02	2,80–4,00	0,50–1,50		0,40	0,20	0,02		0,50	0,05		0,50	Balance	64
ML CuSn	0,01	0,10–0,40	0,10–0,40	0,10		0,50–1,00	0,015		0,03	0,015		0,20	Balance	65
ML CuSn6	0,01				0,10	4,00–7,00	0,02		0,10	0,01–0,40		0,20	Balance	66

Filler metals for arc brazing. CuSi3 and CuAl8 are the usual brazing filler metals for galvanised thin sheet. Which filler metal suits which coating is shown on page 72, as are the old and new standard designations.

Selection of filler metals.

Copper alloys, matching or near-matching base materials

Base material	CuAl8	CuAl9Fe	CuMn13Al7	CuSi3	CuSn	CuSn6	CuAl8Ni2	CuAl8Ni6
2.0040 / OF-Cu				○	●			
2.0070 / SE-Cu				○	●			
2.1030 / Cu Sn8						●		
2.0920 / CuAl8	●							
2.0076 / SW-Cu				○	●			
2.0090 / SF-Cu				○	●			
2.0205 / CuZn0,5				○	●			
2.0220 / CuZn5				●		○		
2.0916 / CuAl5	●							
2.1522 / CuSi2Mn				●				
2.1525 / CuSi3Mn				●				
2.0928 / G-CuAl9	●							
CuAl8Fe3		●						
2.0460 / CuZn20Al	●							
2.0230 / CuZn10				●		○		
2.0240 / CuZn15				●		○		
2.1016 / CuSn4						●		
2.0975 / CuAl10Ni							●	
2.0978 / CuAl11Ni6Fe5								●
2.0980 / CuAl11Ni							●	
CuAl9Fe4Ni1		●						
2.0966 / CuAl10Ni5Fe4								●

● suitable ○ suitable with restrictions

Selection of filler metals.

Stainless steels, matching or near-matching base materials

Typical selection; exact designations are given in the data sheets. Before welding, seam geometry and dilution, heat treatment, service conditions and temperatures must be considered; they may influence the selection beyond these recommendations. We will advise you on other steels and combinations.

Material no.	Designation	ASTM, AISI, UNS	up to °C	1.4316 19.9.LSi	1.4332 24.13.LSi	1.4370 18.8.Mn	1.4430 19.12.3.LSi	1.4462 22.8.3.L	1.4576 19.12.3.NbSi
1.4000	6Cr13	403		●	●	●			
1.4001	7Cr14	429		●	●	●			
1.4002	6CrAl13	405				●			
1.4003	2CrNi12			●		●			
1.4006	12Cr13	410		●		●			
1.4008	GX8CrNi13	CA 15		●		●			
1.4016	6Cr17	430		●		●			
1.4021	20Cr13	420		●		●			
1.4024	15Cr13	410		●		●			
1.4027	X20Cr14	A 217				●			
1.4034	46Cr13					●			
1.4057	17CrNi16-2	431				●			
1.4059	X22CrNi17	A 743				●			
1.4113	6CrMo17-1	434					●		●
1.4120	20CrMo13						●		●
1.4120	X20CrMo13						●		●
1.4122	39CrMo17-1						●		●
1.4122	X35CrMo17-1						●		●
1.4301	5CrNi18-10	304		●					
1.4303	4CrNi18-12	305		●					
1.4306	2CrNi19-11	304L		●					
1.4308	X5CrNi19-10			●					
1.4311	2CrNiN18-10	304LN		●					
1.4312	X10CrNi18-8			●					
1.4362		S32304						●	
1.4401	5CrNiMo17-12-2	316					●		○
1.4404	2CrNiMo17-12-2	316L					●		○

● matching or near-matching filler metal ○ dissimilar or higher-alloyed filler metal (check service conditions). Continued on page 19.

Selection of filler metals.

Stainless steels, continued

Material no.	Designation	ASTM, AISI, UNS	up to °C	1.4316 19.9.LSi	1.4332 24.13.LSi	1.4370 18.8.Mn	1.4430 19.12.3.LSi	1.4462 22.8.3.L	1.4576 19.12.3.NbSi
1.4406	2CrNiMoN17-11-2	316L					●		○
1.4408	X5CrNiMo19-11-2						●		○
1.4409	X2CrNiMo19-11-2						●		○
1.4417		S31500						●	
1.4429	2CrNiMoN17-13-3	316LN					●		○
1.4435	2CrNiMo18-14-3	317L					●		○
1.4436	3CrNiMo17-13-3	S31600					●		○
1.4437	X6CrNiMo18-12	S31600					●		○
1.4462	2CrNiMoN22-5-3	S31803						●	
1.4541	6CrNiTi18-10	321		○					
1.4550	6CrNiNb18-10	347		○					
1.4552	X5CrNiNb19-11	CF8C		○					
1.4571	6CrNiMoTi17-12-2	316 Ti					○		●
1.4580	6CrNiMoNb17-12-2	316 Cb					○		●
1.4581	X5CrNiMoNb19-11-2						○		●
1.4583	10CrNiMoNb18-12	316 Cb					○		●
1.4710[2]			850			○[1]			
1.4712			850			○[1]			
1.4713			800			○[1]			
1.4724		405	850			○[1]			
1.4825		A297, Gr. CF20	800			○[1]			
1.4878		321	800			○[1]			

● matching or near-matching filler metal ○ dissimilar or higher-alloyed filler metal (check service conditions)

[1] Austenitisches Schweißgut mit höherer Duktilität; in schwefelhaltigen Medien oder für farbähnliche Anwendungen sind ähnlich legierte Zusätze erforderlich.
[2] weldability of base material is limited.
[3] For service temperatures up to 400°C.

Dissimilar joints and duplex. Black-and-white joints and selection by Schaeffler diagram: page 98. Selecting the filler metal: page 90.

Wire lengths.

Metres of wire per spool or drum

Calculated from diameter and specific weight. Not every combination of diameter and pack is available; the data sheet is authoritative. Other values: wire length calculator on migal.co.

Aluminium alloys specific weight 2,7 g/cm³

Ø [mm]	g/m	0,5 kg	2 kg	6 kg	7 kg	18 kg	40 kg	80 kg	140 kg	240 kg
0,8	1,36	368	1.474	4.421	5.158	13.263	29.473	58.946	103.156	176.839
1,0	2,12	236	943	2.829	3.301	8.488	18.863	37.726	66.020	113.177
1,2	3,05	164	655	1.965	2.292	5.895	13.099	26.198	45.847	78.595
1,6	5,43	92	368	1.105	1.289	3.316	7.368	14.737	25.789	44.210
2,0	8,48	59	236	707	825	2.122	4.716	9.431	16.505	28.294
2,4	12,21	41	164	491	573	1.474	3.275	6.550	11.462	19.649

Copper alloys specific weight 8,9 g/cm³

Ø [mm]	g/m	5 kg	15 kg	200 kg
0,8	4,47	1.118	3.353	44.706
1,0	6,99	715	2.146	28.612
1,2	10,07	497	1.490	19.870
1,6	17,89	279	838	11.177
2,0	27,96	179	536	7.153
2,4	40,26	124	373	4.967

Stainless steel welding wires specific weight 7,9 g/cm³

Ø [mm]	g/m	15 kg	250 kg
0,8	3,97	3.777	62.957
1,0	6,20	2.418	40.292
1,2	8,93	1.679	27.981
1,6	15,88	944	15.739
2,0	24,82	604	10.073
2,4	35,74	420	6.995

Nickel alloys specific weight 8,5 g/cm³

Ø [mm]	g/m	15 kg
0,8	4,27	3.511
1,0	6,68	2.247
1,2	9,61	1.560
1,6	17,09	878
2,0	26,70	562
2,4	38,45	390

Low-alloy welding wires specific weight 7,85 g/cm³

Ø [mm]	g/m	18 kg	250 kg
0,8	3,95	4.562	63.358
1,0	6,17	2.920	40.549
1,2	8,88	2.027	28.159

Wire length calculator
migal.co/en/products/synopsis/wire-length-calculator

Approvals.

As per migal.co, November 2026

The certificates are available for download on migal.co. Deutsche Bahn approvals: search the DB register under filler metals for the manufacturer MIGAL.CO GmbH.

Aluminium alloys

Filler metal	VdTÜV	DB	DNV-GL	Lloyds Register 2	Bureau Veritas	ABS	KR
MA-4043	●	●					
MA-5087	●	●	●	●	●	●	
MA-5183	●	●	● Ar MIG Ar/He I3 TIG Ar/He I3	● Ar Ar/He I3 TIG Ar/He I3	● Ar Ar/He I3	●	
MA-5356	●	●	●	●	●	●	●
MA-5754	●	●					

Stainless steels and nickel alloys

Filler metal	TÜV-MIG	TÜV-TIG	DB
1.4316 308LSi ML 19.9 LSi	●	●	●
1.4332 309LSi ML 23.12 LSi	●	●	
1.4370 307 ML 18.8 Mn	●		●
1.4430 316LSi ML 19.12.3 LSi	●	●	●
1.4462 2209 ML 22.9.3 NL	●	●	
1.4576 318Si ML 19.12.3 NbSi	●	●	●
2.4831 NiCrMo-3 ML NiCr21Mo9Nb	●	●	

Low-alloy steels

Filler material	TÜV-MIG	TÜV-TIG	DB
69 4 Mn3Ni1CrMo ML-FK1	●		●
1.5424 2Mo ML-Mo	●	●	●
1.7339 CrMo1Si ML-CrMo1	●	●	●
1.7384 CrMo2Si ML-CrMo2	●	●	●
1.5125 3Si1 ML-WSG2		●	●
1.5130 4Si1 ML-WSG3			

Welding rods and wire electrodes

Aluminium alloys.

15 alloys as wire electrodes for MIG welding and as rods for TIG welding. The wire surface is shaved, the diameter monitored by laser and the wire spooled twist-free. Spools are supplied vacuum-packed as standard.



PURE ALUMINIUM

MA-1070	Al99,7	S Al 1070	24
MA-1450	Al99,5Ti	S Al 1450	25

ALUMINIUM-COPPER

MA-2319	AlCu6MnZrTi	S Al 2319	26

ALUMINIUM-SILICON

MA-4018	AlSi7Mg	S Al 4018	27
MA-4020	AlSi3Mn	S Al 4020	28
MA-4043	AlSi5	S Al 4043A	29
MA-4046	AlSi10Mg	S Al 4046	30
MA-4047	AlSi12	S Al 4047A	31

ALUMINIUM-MAGNESIUM

MA-5087	AlMg4,5MnZr	S Al 5087	32
MA-5183	AlMg4,5Mn0,7	S Al 5183	33
MA-5356	AlMg5Cr	S Al 5356	34
MA-5554	AlMg2,7Mn	S Al 5554	35
MA-5556	AlMg5Mn	S Al 5556A	36
MA-5754	AlMg3	S Al 5754	37

ALUMINIUM-MAGNESIUM-SILICON

MA-6063	AlMg0,7SiTiB		38

Which filler metal for which base material? The materials table is on pages 14 and 15, the material calculator on migal.co.

Application notes. Oxide layer, hydrogen, joint preparation and weld defects: notes on welding aluminium from page 41.

All aluminium welding wires
migal.co/en/products/aluminium-welding-wire

MA-1070 Al99,7.

Aluminium welding rod and wire electrode

Typical composition of the filler metal in %

Si	Fe	Cu	Mn	Mg	Zn	Be	Ti	Others	Al
< 0,20	< 0,25	< 0,04	< 0,03	< 0,03	< 0,04	< 0,0003	< 0,03	< 0,03	min. 99,70

Classification

EN ISO 18273	S Al 1070 (Al99,7)
Material no.	3.0259
JIS Z3232	A1070

Physical properties approx. values

Electr. conductivity [S·m/mm²]	34–36
Thermal conductivity, 20 °C [W/(m·K)]	210–230
Thermal expansion, 20–100 °C [1/K]	$23,5 \cdot 10^{-6}$

Notes

Welding of pure Aluminium requires special precautions due to the narrow melting range in order to prevent hotcracking and porosity.

Base materials: see page 15. Application notes from page 41.

Mechanical properties weld metal, approx. values

0,2 % yield strength $R_{p0,2}$ [MPa]	20
Tensile strength R_m [MPa]	65
Elongation A_5 ($L_0 = 5\ d_0$) [%]	35
Test temperature [°C]	20

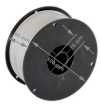
Processing

Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (welding-grade argon, helium or argon-helium mixtures)
Polarity	MIG = +, TIG ~

Dimensions and packaging

MIG wire Ø [mm] 0,8 | 1,0 | 1,2 | 1,6 | 2,0 | 2,4

TIG rod Ø [mm] 1,6 | 2,0 | 2,4 | 3,2 | 4,0 | 5,0


S 100
0,5 kg


S 200
2 kg


S 300
6 kg


B 300
7 kg


BS 300
7 kg


B 400
18 kg


B 400
40 kg

Wire electrodes	Packaging unit
S 100 / 0,5 kg	20 spools = 10 kg (carton)
S 200 / 2 kg	4 spools = 8 kg (carton)
S 300 / 6 kg	56 spools = 336 kg (pallet)
B 300 / BS 300 / 7 kg	56 spools = 392 kg (pallet)
B 400 / 18 kg	28 spools = 504 kg (pallet)
B 400 / 40 kg	15 spools = 600 kg (pallet)

Drums	Packaging unit
Eco drum 80 kg	2 drums = 160 kg (Pallet)
Jumbo drum / 140 kg	2 drums = 280 kg (Pallet)
JumboXL drum / 240 kg	1 drum = 240 kg (Pallet)

TIG rods, 1.000 mm long	Packaging unit
Tube / 2,5 kg	225 tubes = 562,5 kg (pallet)
Carton / 5 kg	120 cartons = 600 kg (pallet)
Carton / 10 kg	60 cartons = 600 kg (pallet)

Current data sheet and stock level
migal.co/en/products/aluminium-welding-wire/ma-1070-al997

Aluminium alloys › Data sheet

MA-1450 Al99,5Ti.

Aluminium welding rod and wire electrode

Typical composition of the filler metal in %

Si	Fe	Cu	Mn	Mg	Zn	Be	Ti	Others	Al
< 0,25	< 0,40	< 0,05	< 0,05	< 0,05	< 0,07	< 0,0003	0,10–0,20	< 0,03	min. 99,50

Classification

EN ISO 18273	S Al 1450 (Al99,5Ti)
Material no.	3.0805

Physical properties approx. values

Electr. conductivity [S·m/mm²]	min. 35
Thermal conductivity, 20 °C [W/(m·K)]	210–230
Thermal expansion, 20–100 °C [1/K]	$23,5 \cdot 10^{-6}$

Mechanical properties weld metal, approx. values

0,2 % yield strength $R_{p0,2}$ [MPa]	20
Tensile strength R_m [MPa]	65
Elongation A_5 ($L_0 = 5\ d_0$) [%]	35
Test temperature [°C]	20

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (welding-grade argon, helium or argon-helium mixtures)
Polarity	MIG = +, TIG ~

Notes

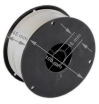
Welding of pure Aluminium requires special precautions due to the narrow melting range in order to prevent hotcracking and porosity. Grain refinement in the weld metal resulting from the addition of Ti.

Base materials: see page 15. Application notes from page 41.

Dimensions and packaging

MIG wire Ø [mm] 0,8 | 1,0 | 1,2 | 1,6 | 2,0 | 2,4

TIG rod Ø [mm] 1,6 | 2,0 | 2,4 | 3,2 | 4,0 | 5,0


S 100
0,5 kg


S 200
2 kg


S 300
6 kg


B 300
7 kg


BS 300
7 kg


B 400
18 kg


B 400
40 kg

Wire electrodes	Packaging unit
S 100 / 0,5 kg	20 spools = 10 kg (carton)
S 200 / 2 kg	4 spools = 8 kg (carton)
S 300 / 6 kg	56 spools = 336 kg (pallet)
B 300 / BS 300 / 7 kg	56 spools = 392 kg (pallet)
B 400 / 18 kg	28 spools = 504 kg (pallet)
B 400 / 40 kg	15 spools = 600 kg (pallet)

Drums	Packaging unit
Eco drum 80 kg	2 drums = 160 kg (Pallet)
Jumbo drum / 140 kg	2 drums = 280 kg (Pallet)
JumboXL drum / 240 kg	1 drum = 240 kg (Pallet)

TIG rods, 1.000 mm long	Packaging unit
Tube / 2,5 kg	225 tubes = 562,5 kg (pallet)
Carton / 5 kg	120 cartons = 600 kg (pallet)
Carton / 10 kg	60 cartons = 600 kg (pallet)

Aluminium

Aluminium alloys › Data sheet

MA-2319 AlCu6MnZrTi.

Aluminium welding rod and wire electrode

Typical composition of the filler metal in %

Si	Fe	Cu	Mn	Mg	V	Zn	Zr	Be	Ti	Others	Others total
< 0,20	< 0,30	5,80–6,80	0,20–0,40	< 0,02	0,05–0,15	< 0,10	0,10–0,25	< 0,0003	0,10–0,20	< 0,05	< 0,15

Classification

EN ISO 18273	S Al 2319 (AlCu6MnZrTi)
AWS A 5.10	ER 2319

Mechanical properties weld metal, approx. values

0,2 % yield strength $R_{p0,2}$ [MPa]	70
Tensile strength R_m [MPa]	160
Elongation A_5 (L_0 = 5 d_0) [%]	12
Test temperature [°C]	20

Notes

This alloy is mainly used in the aerospace industry.

Base materials: see page 15. Application notes from page 41.

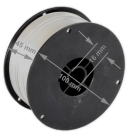
Processing

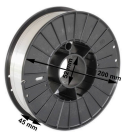
Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (welding-grade argon, helium or argon-helium mixtures)
Polarity	MIG = +, TIG ~

Dimensions and packaging

MIG wire Ø [mm] 0,8 | 1,0 | 1,2 | 1,6 | 2,0 | 2,4

TIG rod Ø [mm] 1,6 | 2,0 | 2,4 | 3,2 | 4,0 | 5,0


S 100
0,5 kg


S 200
2 kg


S 300
6 kg


B 300
7 kg


BS 300
7 kg


B 400
18 kg


B 400
40 kg

Wire electrodes	Packaging unit
S 100 / 0,5 kg	20 spools = 10 kg (carton)
S 200 / 2 kg	4 spools = 8 kg (carton)
S 300 / 6 kg	56 spools = 336 kg (pallet)
B 300 / BS 300 / 7 kg	56 spools = 392 kg (pallet)
B 400 / 18 kg	28 spools = 504 kg (pallet)
B 400 / 40 kg	15 spools = 600 kg (pallet)

Drums	Packaging unit
Jumbo drum / 140 kg	2 drums = 280 kg (Pallet)

TIG rods, 1.000 mm long	Packaging unit
Tube / 2,5 kg	225 tubes = 562,5 kg (pallet)
Carton / 5 kg	120 cartons = 600 kg (pallet)
Carton / 10 kg	60 cartons = 600 kg (pallet)

Current data sheet and stock level
migal.co/en/products/aluminium-welding-wire/ma-2319-alcu6mnzrti

MA-4018 AlSi7Mg.

Aluminium welding rod and wire electrode

Typical composition of the filler metal in %

Si	Fe	Cu	Mn	Mg	Zn	Be	Ti	Others	Others total
6,50–7,50	< 0,20	< 0,05	< 0,10	0,50–0,80	< 0,10	< 0,0003	0,10–0,20	< 0,05	< 0,15

Classification

EN ISO 18273	S Al 4018 (AlSi7Mg)
Material no.	3.2371

Mechanical properties weld metal, approx. values

0,2 % yield strength $R_{p0,2}$ [MPa]	F: 80, T6: 250
Tensile strength R_m [MPa]	F: 140, T6: 310
Elongation A_5 (L_0 = 5 d_0) [%]	F: 2, T6: 4
Test temperature [°C]	20

Notes

Joint and repair welding on castings. The mechanical properties can be improved by heat treatment. Also used for additive manufacturing.

Base materials: see page 15. Application notes from page 41.

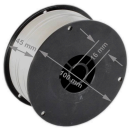
Processing

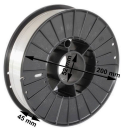
Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (welding-grade argon, helium or argon-helium mixtures)
Polarity	MIG = +, TIG ~

Dimensions and packaging

MIG wire Ø [mm] 1,2 | 1,6 | 2,0 | 2,4

TIG rod Ø [mm] 1,6 | 2,0 | 2,4 | 3,2 | 4,0 | 5,0

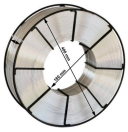

S 100
0,5 kg


S 200
2 kg


S 300
6 kg


B 300
7 kg


BS 300
7 kg


B 400
18 kg


B 400
40 kg

Wire electrodes	Packaging unit
S 100 / 0,5 kg	20 spools = 10 kg (carton)
S 200 / 2 kg	4 spools = 8 kg (carton)
S 300 / 6 kg	56 spools = 336 kg (pallet)
B 300 / BS 300 / 7 kg	56 spools = 392 kg (pallet)
B 400 / 18 kg	28 spools = 504 kg (pallet)
B 400 / 40 kg	15 spools = 600 kg (pallet)

Drums	Packaging unit
Eco drum 80 kg	2 drums = 160 kg (Pallet)
Jumbo drum / 140 kg	2 drums = 280 kg (Pallet)
JumboXL drum / 240 kg	1 drum = 240 kg (Pallet)

TIG rods, 1.000 mm long	Packaging unit
Tube / 2,5 kg	225 tubes = 562,5 kg (pallet)
Carton / 5 kg	120 cartons = 600 kg (pallet)
Carton / 10 kg	60 cartons = 600 kg (pallet)

Current data sheet and stock level
migal.co/en/products/aluminium-welding-wire/ma-4018-alsi7mg

Aluminium alloys › Data sheet

MA-4020 AlSi3Mn.

Aluminium welding rod and wire electrode

Typical composition of the filler metal in %

Si	Fe	Cu	Mn	Mg	Zr	Be	Ti	Others	Others total
2,50–3,50	< 0,20	< 0,03	0,80–1,20	0,01	< 0,01	< 0,0003	< 0,005	< 0,02	< 0,10

Classification

EN ISO 18273	S Al 4020 (AlSi3Mn1)

Mechanical properties

weld metal, approx. values

0,2 % yield strength $R_{p0,2}$ [MPa]	50
Tensile strength R_m [MPa]	120
Elongation A_5 ($L_0 = 5\ d_0$) [%]	25
Test temperature [°C]	20

Notes

Joint welding in the automotive industry especially on outer skin parts in car body construction.

Base materials: see page 15. Application notes from page 41.

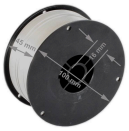
Processing

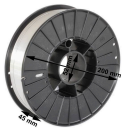
Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (welding-grade argon, helium or argon-helium mixtures)
Polarity	MIG = +, TIG ~

Dimensions and packaging

MIG wire Ø [mm] 0,8 | 1,0 | 1,2 | 1,6 | 2,0 | 2,4

TIG rod Ø [mm] 1,6 | 2,0 | 2,4 | 3,2 | 4,0 | 5,0

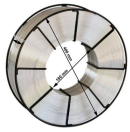

S 100
0,5 kg


S 200
2 kg


S 300
6 kg


B 300
7 kg


BS 300
7 kg


B 400
18 kg


B 400
40 kg

Wire electrodes	Packaging unit
S 100 / 0,5 kg	20 spools = 10 kg (carton)
S 200 / 2 kg	4 spools = 8 kg (carton)
S 300 / 6 kg	56 spools = 336 kg (pallet)
B 300 / BS 300 / 7 kg	56 spools = 392 kg (pallet)
B 400 / 18 kg	28 spools = 504 kg (pallet)
B 400 / 40 kg	15 spools = 600 kg (pallet)

Drums	Packaging unit
Eco drum 80 kg	2 drums = 160 kg (Pallet)
Jumbo drum / 140 kg	2 drums = 280 kg (Pallet)

TIG rods, 1.000 mm long	Packaging unit
Tube / 2,5 kg	225 tubes = 562,5 kg (pallet)
Carton / 5 kg	120 cartons = 600 kg (pallet)
Carton / 10 kg	60 cartons = 600 kg (pallet)

Current data sheet and stock level
migal.co/en/products/aluminium-welding-wire/ma-4020-alsi3mn

MA-4043 AlSi5.

Aluminium welding rod and wire electrode

Typical composition of the filler metal in %

Si	Fe	Cu	Mn	Mg	Zn	Be	Ti	Others	Others total
4,50–6,00	< 0,60	< 0,30	< 0,15	< 0,20	< 0,10	< 0,0003	< 0,15	< 0,05	< 0,15

Classification

EN ISO 18273	S Al 4043A (AlSi5(A))
Material no.	3.2245
AWS A 5.10	ER 4043
JIS Z3232	A4043

Mechanical properties

weld metal, approx. values

0,2 % yield strength $R_{p0,2}$ [MPa]	40
Tensile strength R_m [MPa]	120
Elongation A_5 (L_0 = 5 d_0) [%]	8
Test temperature [°C]	20

Notes

This alloy is particularly used to prevent solidification cracks in connection with high dilution and clamp conditions. Anodizing gives dark colours and is not recommended. The weld pool is very fluid.

Base materials: see page 15. Application notes from page 41.

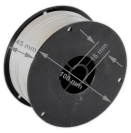
Processing

Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (welding-grade argon, helium or argon-helium mixtures)
Polarity	MIG = +, TIG ~
Approvals	TÜV, DB

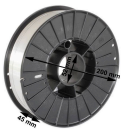
Dimensions and packaging

MIG wire Ø [mm] 0,8 | 1,0 | 1,2 | 1,6 | 2,0 | 2,4

TIG rod Ø [mm] 1,6 | 2,0 | 2,4 | 3,2 | 4,0 | 5,0



S 100
0,5 kg



S 200
2 kg



S 300
6 kg



B 300
7 kg



BS 300
7 kg



B 400
18 kg



B 400
40 kg

Wire electrodes	Packaging unit
S 100 / 0,5 kg	20 spools = 10 kg (carton)
S 200 / 2 kg	4 spools = 8 kg (carton)
S 300 / 6 kg	56 spools = 336 kg (pallet)
B 300 / BS 300 / 7 kg	56 spools = 392 kg (pallet)
B 400 / 18 kg	28 spools = 504 kg (pallet)
B 400 / 40 kg	15 spools = 600 kg (pallet)

Drums	Packaging unit
Eco drum 80 kg	2 drums = 160 kg (Pallet)
Jumbo drum / 140 kg	2 drums = 280 kg (Pallet)
JumboXL drum / 240 kg	1 drum = 240 kg (Pallet)

TIG rods, 1.000 mm long	Packaging unit
Tube / 2,5 kg	225 tubes = 562,5 kg (pallet)
Carton / 5 kg	120 cartons = 600 kg (pallet)
Carton / 10 kg	60 cartons = 600 kg (pallet)

Current data sheet and stock level
migal.co/en/products/aluminium-welding-wire/ma-4043-alsi5

Aluminium alloys › Data sheet

MA-4046 AlSi10Mg.

Aluminium welding rod and wire electrode

Typical composition of the filler metal in %

Si	Fe	Cu	Mn	Mg	Zn	Be	Ti	Others	Others total
9,00–11,00	< 0,50	< 0,03	< 0,40	0,20–0,50	< 0,10	< 0,0003	< 0,15	< 0,05	< 0,15

Classification

EN ISO 18273	S Al 4046 (AlSi10Mg)
Material no.	3.2382

Mechanical properties weld metal, approx. values

0,2 % yield strength $R_{p0,2}$ [MPa]	70
Tensile strength R_m [MPa]	140
Elongation A_5 (L_0 = 5 d_0) [%]	4
Test temperature [°C]	20

Notes

Joint and repair welding on castings. The mechanical properties can be improved by heat treatment. Also used for additive manufacturing.

Base materials: see page 15. Application notes from page 41.

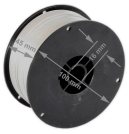
Processing

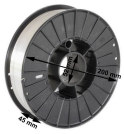
Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (welding-grade argon, helium or argon-helium mixtures)
Polarity	MIG = +, TIG ~

Dimensions and packaging

MIG wire Ø [mm] 1,2 | 1,6 | 2,0 | 2,4

TIG rod Ø [mm] 1,6 | 2,0 | 2,4 | 3,2 | 4,0 | 5,0


S 100
0,5 kg


S 200
2 kg


S 300
6 kg


B 300
7 kg


BS 300
7 kg


B 400
18 kg


B 400
40 kg

Wire electrodes	Packaging unit
S 100 / 0,5 kg	20 spools = 10 kg (carton)
S 200 / 2 kg	4 spools = 8 kg (carton)
S 300 / 6 kg	56 spools = 336 kg (pallet)
B 300 / BS 300 / 7 kg	56 spools = 392 kg (pallet)
B 400 / 18 kg	28 spools = 504 kg (pallet)
B 400 / 40 kg	15 spools = 600 kg (pallet)

Drums	Packaging unit
Eco drum 80 kg	2 drums = 160 kg (Pallet)
Jumbo drum / 140 kg	2 drums = 280 kg (Pallet)

TIG rods, 1.000 mm long	Packaging unit
Tube / 2,5 kg	225 tubes = 562,5 kg (pallet)
Carton / 5 kg	120 cartons = 600 kg (pallet)
Carton / 10 kg	60 cartons = 600 kg (pallet)

Current data sheet and stock level
migal.co/en/products/aluminium-welding-wire/ma-4046-alsi10mg

Aluminium alloys › Data sheet

MA-4047 AlSi12.

Aluminium welding rod and wire electrode

Typical composition of the filler metal in %

Si	Fe	Cu	Mn	Mg	Zn	Be	Ti	Others	Others total
11,00–13,00	< 0,60	< 0,30	< 0,15	< 0,15	< 0,20	< 0,0003	< 0,15	< 0,05	< 0,15

Classification

EN ISO 18273	S Al 4047A (AlSi12(A))
Material no.	3.2585
AWS A 5.10	ER 4047
JIS Z3232	A4047

Mechanical properties weld metal, approx. values

0,2 % yield strength $R_{p0,2}$ [MPa]	60
Tensile strength R_m [MPa]	130
Elongation A_5 (L_0 = 5 d_0) [%]	5
Test temperature [°C]	20

Notes

This alloy ist particularly used to prevent solidification cracks in connection with high dilution and clamp conditions. Anodizing gives dark gray colours and is not recommended.

Base materials: see page 15. Application notes from page 41.

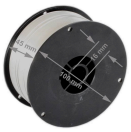
Processing

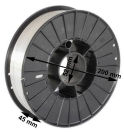
Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (welding-grade argon, helium or argon-helium mixtures)
Polarity	MIG = +, TIG ~

Dimensions and packaging

MIG wire Ø [mm] 0,8 | 1,0 | 1,2 | 1,6 | 2,0 | 2,4

TIG rod Ø [mm] 1,6 | 2,0 | 2,4 | 3,2 | 4,0 | 5,0


S 100
0,5 kg


S 200
2 kg


S 300
6 kg


B 300
7 kg


BS 300
7 kg


B 400
18 kg


B 400
40 kg

Wire electrodes	Packaging unit
S 100 / 0,5 kg	20 spools = 10 kg (carton)
S 200 / 2 kg	4 spools = 8 kg (carton)
S 300 / 6 kg	56 spools = 336 kg (pallet)
B 300 / BS 300 / 7 kg	56 spools = 392 kg (pallet)
B 400 / 18 kg	28 spools = 504 kg (pallet)
B 400 / 40 kg	15 spools = 600 kg (pallet)

Drums	Packaging unit
Eco drum 80 kg	2 drums = 160 kg (Pallet)
Jumbo drum / 140 kg	2 drums = 280 kg (Pallet)

TIG rods, 1.000 mm long	Packaging unit
Tube / 2,5 kg	225 tubes = 562,5 kg (pallet)
Carton / 5 kg	120 cartons = 600 kg (pallet)
Carton / 10 kg	60 cartons = 600 kg (pallet)

Aluminium

Current data sheet and stock level
migal.co/en/products/aluminium-welding-wire/ma-4047-alsi12

Aluminium alloys › Data sheet

MA-5087 AlMg4,5MnZr.

Aluminium welding rod and wire electrode

Typical composition of the filler metal in %

Si	Fe	Cu	Mn	Mg	Cr	Zn	Be	Ti	Zr	Others	Others total
< 0,25	< 0,40	< 0,05	0,70–1,10	4,50–5,20	0,05–0,25	< 0,25	< 0,0003	< 0,15	0,10–0,20	< 0,05	< 0,15

Classification

EN ISO 18273	S Al 5087 (AlMg4,5MnZr(A))
Material no.	3.3546

Mechanical properties weld metal, approx. values

0,2 % yield strength $R_{p0,2}$ [MPa]	140
Tensile strength R_m [MPa]	285
Elongation A_5 (L_0 = 5 d_0) [%]	18
Test temperature [°C]	20

Notes

The weld metal is insensitive to hot cracking; particularly advantageous in unfavourable clamping conditions with complicated workpieces.

Base materials: see page 15. Application notes from page 41.

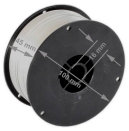
Processing

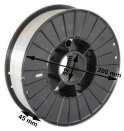
Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (welding-grade argon, helium or argon-helium mixtures)
Polarity	MIG = +, TIG ~
Approvals	TÜV, DB, Lloyds Register, DNV-GL, Bureau Veritas, ABS

Dimensions and packaging

MIG wire Ø [mm] 0,8 | 1,0 | 1,2 | 1,6 | 2,0 | 2,4

TIG rod Ø [mm] 1,6 | 2,0 | 2,4 | 3,2 | 4,0 | 5,0

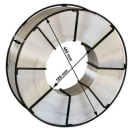

S 100
0,5 kg


S 200
2 kg


S 300
6 kg


B 300
7 kg


BS 300
7 kg


B 400
18 kg


B 400
40 kg

Wire electrodes	Packaging unit
S 100 / 0,5 kg	20 spools = 10 kg (carton)
S 200 / 2 kg	4 spools = 8 kg (carton)
S 300 / 6 kg	56 spools = 336 kg (pallet)
B 300 / BS 300 / 7 kg	56 spools = 392 kg (pallet)
B 400 / 18 kg	28 spools = 504 kg (pallet)
B 400 / 40 kg	15 spools = 600 kg (pallet)

Drums	Packaging unit
Jumbo drum / 140 kg	2 drums = 280 kg (Pallet)
JumboXL drum / 240 kg	1 drum = 240 kg (Pallet)

TIG rods, 1.000 mm long	Packaging unit
Tube / 2,5 kg	225 tubes = 562,5 kg (pallet)
Carton / 5 kg	120 cartons = 600 kg (pallet)
Carton / 10 kg	60 cartons = 600 kg (pallet)

Current data sheet and stock level
migal.co/en/products/aluminium-welding-wire/ma-5087-almg45mnzr

Aluminium alloys › Data sheet

MA-5183 AlMg4,5Mn0,7.

Aluminium welding rod and wire electrode

Typical composition of the filler metal in %

Si	Fe	Cu	Mn	Mg	Cr	Zn	Be	Ti	Others	Others total
< 0,40	< 0,40	< 0,10	0,50–1,00	4,30–5,20	0,05–0,25	< 0,25	< 0,0003	< 0,15	< 0,05	< 0,15

Classification

EN ISO 18273	S Al 5183 (AlMg4,5Mn0,7(A))
Material no.	3.3548
AWS A 5.10	ER 5183
JIS Z3232	A5183

Notes

Seawater resistant weld metal.

Base materials: see page 15. Application notes from page 41.

Approvals

TÜV, DB
MIG-Argon: Lloyds Register , DNV-GL , Bureau Veritas , ABS
TIG-Ar/He I3: DNV-GL , Lloyds Register

Mechanical properties weld metal, approx. values

0,2 % yield strength $R_{p0,2}$ [MPa]	130
Tensile strength R_m [MPa]	275
Elongation A_5 (L_0 = 5 d_0) [%]	18
Test temperature [°C]	20

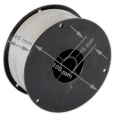
Processing

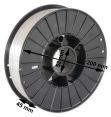
Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (welding-grade argon, helium or argon-helium mixtures)
Polarity	MIG = +, TIG ~

Dimensions and packaging

MIG wire Ø [mm] 0,8 | 1,0 | 1,2 | 1,6 | 2,0 | 2,4

TIG rod Ø [mm] 1,6 | 2,0 | 2,4 | 3,2 | 4,0 | 5,0


S 100
0,5 kg


S 200
2 kg


S 300
6 kg


B 300
7 kg


BS 300
7 kg


B 400
18 kg


B 400
40 kg

Wire electrodes	Packaging unit
S 100 / 0,5 kg	20 spools = 10 kg (carton)
S 200 / 2 kg	4 spools = 8 kg (carton)
S 300 / 6 kg	56 spools = 336 kg (pallet)
B 300 / BS 300 / 7 kg	56 spools = 392 kg (pallet)
B 400 / 18 kg	28 spools = 504 kg (pallet)
B 400 / 40 kg	15 spools = 600 kg (pallet)

Drums	Packaging unit
Jumbo drum / 140 kg	2 drums = 280 kg (Pallet)
JumboXL drum / 240 kg	1 drum = 240 kg (Pallet)

TIG rods, 1.000 mm long	Packaging unit
Tube / 2,5 kg	225 tubes = 562,5 kg (pallet)
Carton / 5 kg	120 cartons = 600 kg (pallet)
Carton / 10 kg	60 cartons = 600 kg (pallet)

Aluminium

Aluminium alloys › Data sheet

MA-5356 AlMg5Cr.

Aluminium welding rod and wire electrode

Typical composition of the filler metal in %

Si	Fe	Cu	Mn	Mg	Cr	Zn	Be	Ti	Others	Others total
< 0,25	< 0,40	< 0,10	0,05–0,20	4,50–5,50	0,05–0,20	< 0,10	< 0,0003	0,06–0,20	< 0,05	< 0,15

Classification

EN ISO 18273	S Al 5356 (AlMg5Cr(A))
Material no.	3.3556
AWS A 5.10	ER 5356
JIS Z3232	A5356

Mechanical properties weld metal, approx. values

0,2 % yield strength $R_{p0,2}$ [MPa]	120
Tensile strength R_m [MPa]	250
Elongation A_5 (L_0 = 5 d_0) [%]	18
Test temperature [°C]	20

Notes

The weld metal is seawater resistant. Suitable for nearly colour-matched welds on anodic oxidisable (anodised) materials.

Base materials: see page 15. Application notes from page 41.

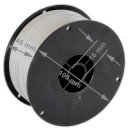
Processing

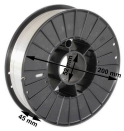
Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (welding-grade argon, helium or argon-helium mixtures)
Polarity	MIG = +, TIG ~
Approvals	TÜV, DB, Lloyds Register, DNV-GL, Bureau Veritas, ABS, KR

Dimensions and packaging

MIG wire Ø [mm] 0,8 | 1,0 | 1,2 | 1,6 | 2,0 | 2,4

TIG rod Ø [mm] 1,6 | 2,0 | 2,4 | 3,2 | 4,0 | 5,0

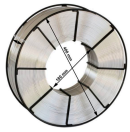

S 100
0,5 kg


S 200
2 kg


S 300
6 kg


B 300
7 kg


BS 300
7 kg


B 400
18 kg


B 400
40 kg

Wire electrodes	Packaging unit
S 100 / 0,5 kg	20 spools = 10 kg (carton)
S 200 / 2 kg	4 spools = 8 kg (carton)
S 300 / 6 kg	56 spools = 336 kg (pallet)
B 300 / BS 300 / 7 kg	56 spools = 392 kg (pallet)
B 400 / 18 kg	28 spools = 504 kg (pallet)
B 400 / 40 kg	15 spools = 600 kg (pallet)

Drums	Packaging unit
Jumbo drum / 140 kg	2 drums = 280 kg (Pallet)
JumboXL drum / 240 kg	1 drum = 240 kg (Pallet)

TIG rods, 1.000 mm long	Packaging unit
Tube / 2,5 kg	225 tubes = 562,5 kg (pallet)
Carton / 5 kg	120 cartons = 600 kg (pallet)
Carton / 10 kg	60 cartons = 600 kg (pallet)

Current data sheet and stock level
migal.co/en/products/aluminium-welding-wire/ma-5356-almg5cr

Aluminium alloys › Data sheet

MA-5554 AlMg2,7Mn.

Aluminium welding rod and wire electrode

Typical composition of the filler metal in %

Si	Fe	Cu	Mn	Mg	Cr	Zn	Be	Ti	Others	Others total
< 0,25	< 0,40	< 0,10	0,50–1,00	2,40–3,00	0,05–0,20	< 0,25	< 0,0003	0,05–0,20	< 0,05	< 0,15

Classification

EN ISO 18273	S Al 5554 (AlMg2,7Mn)
Material no.	3.3538
AWS A 5.10	ER 5554
JIS Z3232	A5554

Mechanical properties weld metal, approx. values

0,2 % yield strength $R_{p0,2}$ [MPa]	100
Tensile strength R_m [MPa]	215
Elongation A_5 (L_0 = 5 d_0) [%]	18
Test temperature [°C]	20

Notes

This alloy was developed for applications at high temperatures and for resistance against intergranular corrosion. Joining of the base metal 5454 with alloys of the 6000 range is possible. The weld metal is sea water resistant.

Base materials: see page 15. Application notes from page 41.

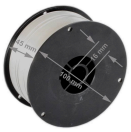
Processing

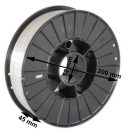
Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (welding-grade argon, helium or argon-helium mixtures)
Polarity	MIG = +, TIG ~

Dimensions and packaging

MIG wire Ø [mm] 0,8 | 1,0 | 1,2 | 1,6 | 2,0 | 2,4

TIG rod Ø [mm] 1,6 | 2,0 | 2,4 | 3,2 | 4,0 | 5,0


S 100
0,5 kg


S 200
2 kg


S 300
6 kg


B 300
7 kg


BS 300
7 kg


B 400
18 kg


B 400
40 kg

Wire electrodes	Packaging unit
S 100 / 0,5 kg	20 spools = 10 kg (carton)
S 200 / 2 kg	4 spools = 8 kg (carton)
S 300 / 6 kg	56 spools = 336 kg (pallet)
B 300 / BS 300 / 7 kg	56 spools = 392 kg (pallet)
B 400 / 18 kg	28 spools = 504 kg (pallet)
B 400 / 40 kg	15 spools = 600 kg (pallet)

Drums	Packaging unit
Jumbo drum / 140 kg	2 drums = 280 kg (Pallet)
JumboXL drum / 240 kg	1 drum = 240 kg (Pallet)

TIG rods, 1.000 mm long	Packaging unit
Tube / 2,5 kg	225 tubes = 562,5 kg (pallet)
Carton / 5 kg	120 cartons = 600 kg (pallet)
Carton / 10 kg	60 cartons = 600 kg (pallet)

Aluminium

Current data sheet and stock level
migal.co/en/products/aluminium-welding-wire/ma-5554-almg27mn

Aluminium alloys › Data sheet

MA-5556 AlMg5Mn.

Aluminium welding rod and wire electrode

Typical composition of the filler metal in %

Si	Fe	Cu	Mn	Mg	Cr	Zn	Be	Ti	Others	Others total
< 0,25	< 0,40	< 0,10	0,60–1,00	5,00–5,50	0,05–0,20	< 0,20	< 0,0003	0,05–0,20	< 0,05	< 0,15

Classification

EN ISO 18273	S Al 5556A (AlMg5Mn1(A))
AWS A 5.10	ER 5556

Mechanical properties weld metal, approx. values

0,2 % yield strength $R_{p0,2}$ [MPa]	145
Tensile strength R_m [MPa]	290
Elongation A_5 (L_0 = 5 d_0) [%]	17
Test temperature [°C]	20

Notes

This alloy has the highest strength. The weld metal is seawater resistant.

Base materials: see page 15. Application notes from page 41.

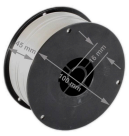
Processing

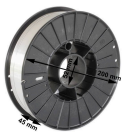
Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (welding-grade argon, helium or argon-helium mixtures)
Polarity	MIG = +, TIG ~

Dimensions and packaging

MIG wire Ø [mm] 0,8 | 1,0 | 1,2 | 1,6 | 2,0 | 2,4

TIG rod Ø [mm] 1,6 | 2,0 | 2,4 | 3,2 | 4,0 | 5,0


S 100
0,5 kg


S 200
2 kg


S 300
6 kg


B 300
7 kg


BS 300
7 kg


B 400
18 kg


B 400
40 kg

Wire electrodes	Packaging unit
S 100 / 0,5 kg	20 spools = 10 kg (carton)
S 200 / 2 kg	4 spools = 8 kg (carton)
S 300 / 6 kg	56 spools = 336 kg (pallet)
B 300 / BS 300 / 7 kg	56 spools = 392 kg (pallet)
B 400 / 18 kg	28 spools = 504 kg (pallet)
B 400 / 40 kg	15 spools = 600 kg (pallet)

Drums	Packaging unit
Jumbo drum / 140 kg	2 drums = 280 kg (Pallet)
JumboXL drum / 240 kg	1 drum = 240 kg (Pallet)

TIG rods, 1.000 mm long	Packaging unit
Tube / 2,5 kg	225 tubes = 562,5 kg (pallet)
Carton / 5 kg	120 cartons = 600 kg (pallet)
Carton / 10 kg	60 cartons = 600 kg (pallet)

Current data sheet and stock level
migal.co/en/products/aluminium-welding-wire/ma-5556-almg5mn

Aluminium alloys › Data sheet

MA-5754 AlMg3.

Aluminium welding rod and wire electrode

Typical composition of the filler metal in %

Si	Fe	Cu	Mn	Mg	Cr	Zn	Be	Ti	Others	Others total
< 0,40	< 0,40	< 0,10	< 0,50	2,60–3,60	< 0,30	< 0,20	< 0,0003	< 0,15	< 0,05	< 0,15

Classification

EN ISO 18273	S Al 5754 (AlMg3)
Material no.	3.3536

Mechanical properties weld metal, approx. values

0,2 % yield strength $R_{p0,2}$ [MPa]	80
Tensile strength R_m [MPa]	190
Elongation A_5 (L_0 = 5 d_0) [%]	20
Test temperature [°C]	20

Notes

The weld metal is seawater resistant. Suitable for nearly colour-matched welds on anodic oxidisable (anodised) materials.

Base materials: see page 15. Application notes from page 41.

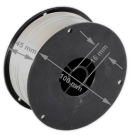
Processing

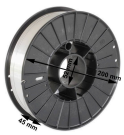
Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (welding-grade argon, helium or argon-helium mixtures)
Polarity	MIG = +, TIG ~
Approvals	TÜV, DB

Dimensions and packaging

MIG wire Ø [mm] 0,8 | 1,0 | 1,2 | 1,6 | 2,0 | 2,4

TIG rod Ø [mm] 1,6 | 2,0 | 2,4 | 3,2 | 4,0 | 5,0


S 100
0,5 kg


S 200
2 kg


S 300
6 kg


B 300
7 kg


BS 300
7 kg


B 400
18 kg


B 400
40 kg

Wire electrodes	Packaging unit
S 100 / 0,5 kg	20 spools = 10 kg (carton)
S 200 / 2 kg	4 spools = 8 kg (carton)
S 300 / 6 kg	56 spools = 336 kg (pallet)
B 300 / BS 300 / 7 kg	56 spools = 392 kg (pallet)
B 400 / 18 kg	28 spools = 504 kg (pallet)
B 400 / 40 kg	15 spools = 600 kg (pallet)

Drums	Packaging unit
Jumbo drum / 140 kg	2 drums = 280 kg (Pallet)
JumboXL drum / 240 kg	1 drum = 240 kg (Pallet)

TIG rods, 1.000 mm long	Packaging unit
Tube / 2,5 kg	225 tubes = 562,5 kg (pallet)
Carton / 5 kg	120 cartons = 600 kg (pallet)
Carton / 10 kg	60 cartons = 600 kg (pallet)

Aluminium

Aluminium alloys › Data sheet

MA-6063 AlMg0,7SiTiB.

Aluminium welding rod and wire electrode

Typical composition of the filler metal in %

Si	Fe	Cu	Mn	Mg	Cr	Zn	Be	Ti	B	Others	Others total
0,20–0,60	< 0,35	< 0,10	< 0,10	0,45–0,90	< 0,10	< 0,10	< 0,0003	0,20–0,30	0,04–0,06	< 0,05	< 0,15

Notes

First near-matching filler metal for aluminium alloys of the 6000 series (AlMgSi), with a Ti5B1 content of approx. 0,30 %. Suitable for joint welding and additive manufacturing (WAAM). The strength can be increased by subsequent heat treatment.

Base materials: see page 15. Application notes from page 41. Background and comparison with 4043 and 5183 on pages 39 and 40.

Mechanical properties

weld metal, approx. values

0,2 % yield strength $R_{p0,2}$ [MPa]	F: 80, T6: 200–260
Tensile strength R_m [MPa]	F: 150, T6: 250–280
Elongation A_5 (L_0 = 5 d_0) [%]	F: 15, T6: 6–12
Test temperature [°C]	20

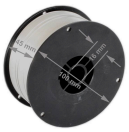
Processing

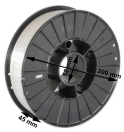
Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (welding-grade argon, helium or argon-helium mixtures)
Polarity	MIG = +, TIG ~

Dimensions and packaging

MIG wire Ø [mm] 0,8 | 1,0 | 1,2 | 1,6 | 2,0 | 2,4

TIG rod Ø [mm] 1,6 | 2,0 | 2,4 | 3,2 | 4,0 | 5,0


S 100
0,5 kg


S 200
2 kg


S 300
6 kg


B 300
7 kg


BS 300
7 kg


B 400
18 kg


B 400
40 kg

Wire electrodes	Packaging unit
S 100 / 0,5 kg	20 spools = 10 kg (carton)
S 200 / 2 kg	4 spools = 8 kg (carton)
S 300 / 6 kg	56 spools = 336 kg (pallet)
B 300 / BS 300 / 7 kg	56 spools = 392 kg (pallet)
B 400 / 18 kg	28 spools = 504 kg (pallet)
B 400 / 40 kg	15 spools = 600 kg (pallet)

Drums	Packaging unit
Eco drum 80 kg	2 drums = 160 kg (Pallet)
Jumbo drum / 140 kg	2 drums = 280 kg (Pallet)

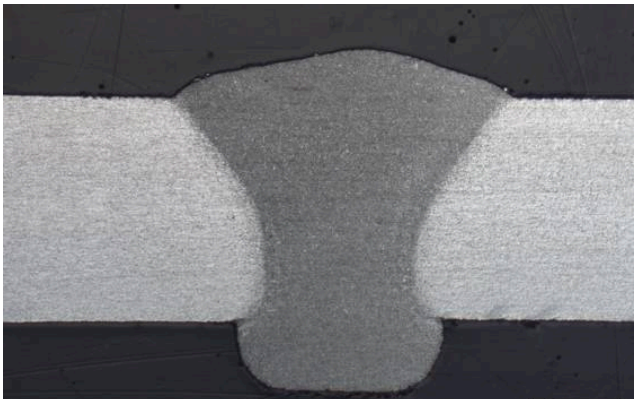
TIG rods, 1.000 mm long	Packaging unit
Tube / 2,5 kg	225 tubes = 562,5 kg (pallet)
Carton / 5 kg	120 cartons = 600 kg (pallet)
Carton / 10 kg	60 cartons = 600 kg (pallet)

Current data sheet and stock level
migal.co/en/products/aluminium-welding-wire/ma-6063-almg07sitib

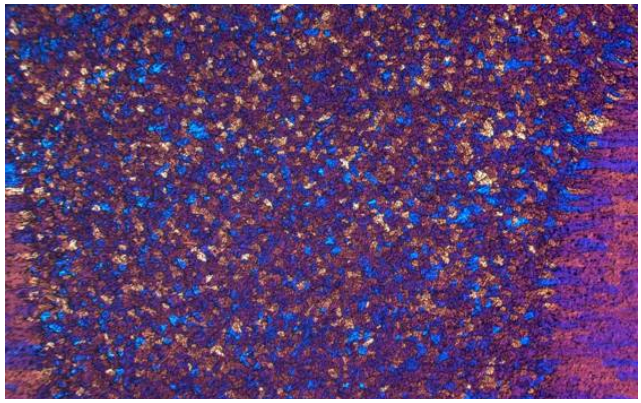
MA-6063 AlMg0,7SiTiB.

Near-matching welding in the 6000 series

For decades there was no near-matching filler metal for aluminium alloys of the 6000 series (AlMgSi). MA-6063, with a Ti5B1 content of approx. 0,30 %, closes this gap.



Macrosection: base material AW-6082, 5 mm, filler metal MA-6063 1,2 mm



Fine-grained structure through TiB particles

Why there was no near-matching filler metal until now

When selecting a filler metal for joint welding, a near-matching alloy is normally chosen. This applies to steels as well as to non-ferrous metals. Burn-off of alloying elements, especially in processes with droplet transfer through the arc, is compensated by a slightly higher content of these alloying elements.

For aluminium alloys of the 6000 series (AlMgSi), this principle has been departed from for decades. Although this alloy group is widely used (bumpers and car bodies in automotive engineering, large profiles in rail vehicle construction), there has so far been no near-matching filler metal. The reason is the high hot cracking susceptibility of aluminium alloys, with a maximum at alloy contents of 1,2 % magnesium and about 0,75 % silicon. These are roughly the alloy ranges of the 6000 series.

For example, it is not possible to weld these alloys with the TIG process without filler metal, as hot cracks always form.

The previous compromise

Until now, the only way out was to raise the magnesium or silicon content of the weld with filler metals of the 4000 or 5000 series containing approx. 5 % Mg or Si far enough to avoid the range prone to hot cracking. This compromise naturally involves various advantages and disadvantages.

Grain refinement by Ti5B1

A way out of this dilemma was shown by the doctoral thesis of Dipl.-Ing. Philipp Schempp, TU Berlin 2013, entitled “Grain refinement in aluminium GTA welds”. It describes how the formation of hot cracks in aluminium alloys is reliably avoided by adding Ti5B1 particles. As the melt cools, these nanoparticles act as heterogeneous solidification nuclei and lead to a very marked reduction in grain size. This at the same time prevents hot cracks from forming.

MIGAL.CO has succeeded in making a first filler metal of the 6000 series with a Ti5B1 content of approx. 0,30 % commercially available. MA-6063 is available as a MIG wire electrode and as a TIG rod. It is suitable for joint welding and for additive manufacturing (WAAM).

Current data sheet and video
migal.co/en/products/aluminium-welding-wire/ma-6063-almg07sitib

MA-6063 AlMg0,7SiTiB.

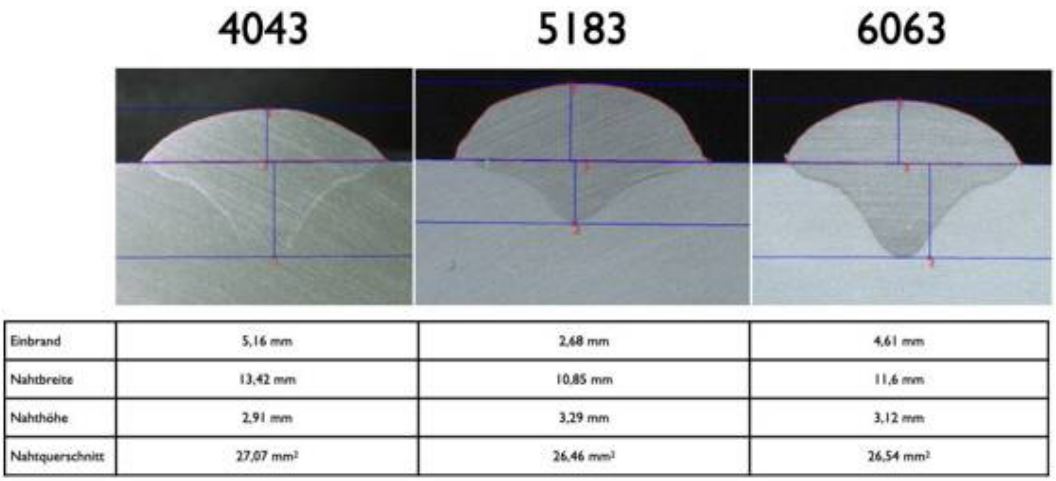
Near-matching welding in the 6000 series

What MA-6063 does better

The advantages are shown by the comparison with the filler metals 4043 and 5183 used so far. A key point is the possibility of increasing the strength by subsequent heat treatment. This gives a yield strength of 200 to 260 MPa combined with good elongation values of 6 to 12 %.

Weldability (seam geometry, penetration depth, black deposit) is also improved very considerably compared with the AlMg alloy. The penetration profile of MA-6063 is almost identical to that of 4043 (AlSi5), which is a great advantage for many applications.

Weld shape and penetration compared



	4043	5183	6063
Einbrand	5,16 mm	2,68 mm	4,61 mm
Nahtbreite	13,42 mm	10,85 mm	11,6 mm
Nahthöhe	2,91 mm	3,29 mm	3,12 mm
Nahtquerschnitt	27,07 mm²	26,46 mm²	26,54 mm²

Comparison of weld shape and penetration: 4043, 5183 and 6063

Comparison of filler metals for 6xxx base materials

	4043	5183	6063
Black deposit	+	–	+
Penetration depth	+	–	+
Ductility	–	+	+
Seam geometry	+	–	+
Strength	–	+	• (weld metal) / + (T6)
Hot cracking	+	–	+
Thermal conductivity	•	–	+
Electrical conductivity	•	–	+
Coating, painting	k. A.	–	+

+ favourable • medium – unfavourable n/s = not specified. Data sheet of MA-6063 on page 38.

Current data sheet and video
migal.co/en/products/aluminium-welding-wire/ma-6063-almg07sitib

Aluminium is different from steel.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHY CAN ALUMINIUM NOT BE WELDED LIKE STEEL?

Aluminium conducts heat around three times as well as steel, expands twice as much and melts at just 660 °C. Its oxide skin, by contrast, melts only at around 2,050 °C, and the molten metal absorbs hydrogen, which forms pores during solidification. Anyone who welds aluminium with habits from steel fabrication gets lack of fusion, distortion, oxide inclusions and porosity.

Property	Unit	Aluminium (Al)	Iron (Fe)	Ratio Al : Fe
Atomic weight	g/mol	26,98	55,84	≈ 1 : 2
Crystal lattice	–	face-centred cubic	body-centred cubic	–
Density	g/cm³	2,70	7,87	≈ 1 : 3
Young's modulus	GPa	67	210	≈ 1 : 3
Coefficient of thermal expansion	10^{-6}/K	24	12	≈ 2 : 1
Yield strength Rp0.2	MPa	≈ 10	≈ 100	≈ 1 : 10
Tensile strength Rm	MPa	≈ 50	≈ 200	≈ 1 : 4
Specific heat	J/(kg·K)	≈ 890	≈ 460	≈ 2 : 1
Heat of fusion	J/g	≈ 390	≈ 272	≈ 1,5 : 1
Melting point	°C (K)	660 (933)	1.538 (1.811)	≈ 1 : 2
Heat conductivity	W/(m·K)	235	75	≈ 3 : 1
Electrical conductivity	MS/m	38	≈ 10	≈ 4 : 1
Oxides	–	Al_2O_3	FeO / Fe_2O_3 / Fe_3O_4	–
Melting point of the oxides	°C	2.050	1.400 / 1.455 / 1.600	for Fe similar to the metal, for Al around three times as high
Density of the oxides	g/cm³	3,89	5,7 / 5,2 / ≈ 5,0	Fe oxides lighter than steel, Al oxide heavier than aluminium

The use of aluminium and its alloys has been growing for years, above all in vehicle, rail vehicle and shipbuilding. Lightweight construction saves energy in operation. That is why fabricators are switching from steel to aluminium, or new companies start with aluminium straight away.

The processes and terms often differ only slightly from steel: MIG instead of MAG, TIG as usual, and the equipment looks similar. That is exactly what tempts people to treat aluminium like steel. In fact, many properties behave in almost opposite ways. Knowing them avoids costly rework, scrap and delays. This page gives an overview; the articles at the end go into the individual topics in depth.

Where does porosity in aluminium welds come from?

Liquid aluminium dissolves around twenty times more hydrogen than solid aluminium. On solidification the hydrogen is released abruptly, and whatever can no longer escape remains as a pore in the weld. The main sources are moisture in the oxide layer, condensation, grease and dirt on workpiece and wire, and moisture in the shielding gas.

- Store workpieces and wire dry and do not bring them cold into a warm, humid workshop. Whether condensation forms is shown by the dew point calculator; background under Condensation (page 45).
- Clean surfaces shortly before welding and keep opened wire spools protected.
- Keep gas hoses and torch leak-tight, because moist shielding gas carries hydrogen straight into the arc.

The physics behind it is explained in Solubility of hydrogen (page 43).

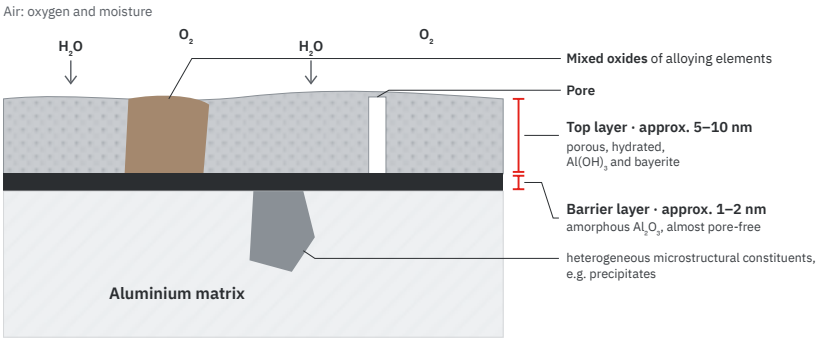
Also in the full article on migal.co: What does the high thermal conductivity do in welding · Why does aluminium distort more, and does rigid clamping help · Why is the oxide layer the real problem · Why is wire feeding critical with aluminium · Why is arc ignition more difficult with aluminium · Which filler metal suits which aluminium alloy

Oxide layer.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHAT IS THE OXIDE LAYER ON ALUMINIUM?

In air, aluminium is immediately covered by a layer of aluminium oxide (Al_2O_3). It is only a few nanometres thick, yet it reliably protects the metal against further corrosion. In welding it is the most important source of trouble: it melts only at around 2,050 °C, it is heavier than the molten metal and it binds moisture.



Schematic, not to scale.

Aufbau der natürlichen Oxidschicht auf Aluminium

Every bare aluminium surface, whether brushed, milled or freshly drawn, is covered by this layer again after a short time. It cannot be removed permanently. What matters for welding is to reduce it to a thin, uniform layer shortly beforehand.

Why does the oxide layer cause weld defects?

Aluminium oxide melts only at around 2,050 °C, aluminium already at 660 °C. The oxide skin therefore stays solid in the weld pool, breaks up and ends up in the weld. With a density of 3.9 g/cm³ it is heavier than the melt, so it does not float to the top like oxides in steel but sinks. The results are oxide inclusions, lack of fusion and brittle areas.

In steel, the melting points of oxide and metal are close together, and iron oxides are lighter than steel. They rise to the surface as slag. With aluminium, by contrast, the oxide layer must be thin and clean before welding and has to be broken up by the arc during welding.

How does the oxide layer affect the arc?

When welding aluminium, the arc needs oxide: its cathode spots preferentially attach to the oxide and break up the oxide skin. This is the cleaning action with the electrode connected to the positive pole. If the thickness and condition of the oxide layer change, the arc and the weld change too.

In MIG and TIG welding, the surface condition affects

- the stability of the arc,
- the geometry of the cathode spot,
- the voltage drop in the arc and thus the arc length,
- the weld geometry and weld quality,
- reproducibility, especially in mechanised and robotic welding.

In MIG welding the wire electrode is therefore connected to the positive pole. In AC TIG welding the positive half-wave provides the cleaning, while the negative half-wave relieves the tungsten electrode. The cleaning is visible as a bright band beside the weld. More on starting the arc under Arc ignition (page 49).

Why does oxide lead to porosity?

For two reasons. The porous top layer binds water, which breaks down into hydrogen in the arc. And oxide films in the melt are the places where dissolved hydrogen preferentially collects into pores during solidification. More oxide therefore means more porosity, even at the same hydrogen content.

Research from foundry technology shows that hydrogen pores can practically not form on their own in liquid aluminium. They grow on folded-in oxide films, so-called bifilms, which contain a fine gap. Hydrogen supplies the gas, oxide supplies the site. In practice this means: keep oxide and moisture low together, on the workpiece and on the wire.

Background under Solubility of hydrogen (page 43) and Condensation (page 45).

Also in the full article on migal.co: Is aluminium oxide dense · How do you remove the oxide layer before welding · What role does the oxide layer on the welding wire play

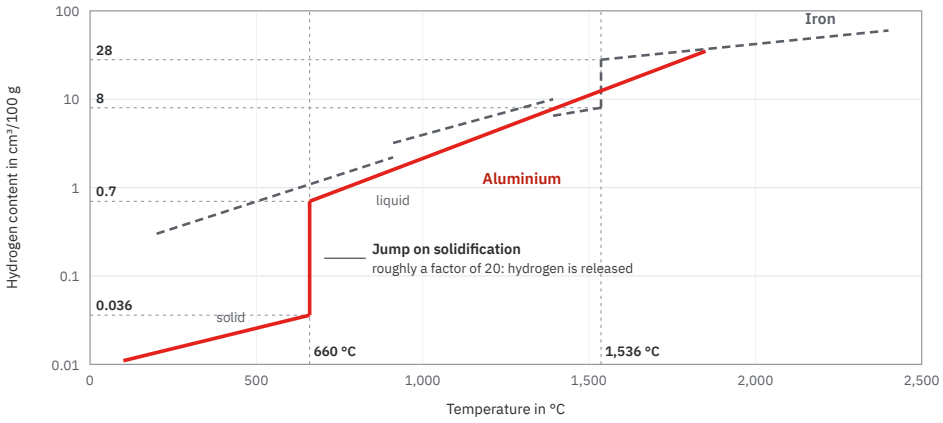
Full article on migal.co
migal.co/en/service/welding-of-aluminium/oxide-layer

Hydrogen and pores.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHY DO HYDROGEN PORES FORM WHEN WELDING ALUMINIUM?

Hydrogen is the only gas that dissolves in aluminium. At the melting point, liquid aluminium takes up around 0.7 cm³ per 100 g, solid aluminium only about 0.036 cm³, roughly twenty times less. When the weld solidifies, the hydrogen is therefore released abruptly. Whatever can no longer escape remains as a pore in the weld metal.



Schematic, based on literature values, at 1 bar hydrogen partial pressure. Aluminium red, iron grey dashed.

Solubility of hydrogen in aluminium and iron as a function of temperature

Because aluminium solidifies quickly, the gas has little time to rise. Hydrogen pores can therefore hardly be avoided completely in MIG welding of aluminium. The aim is to keep them so small and so rare that the weld reaches the required quality level.

How much hydrogen does aluminium dissolve?

The solubility depends on temperature, alloy and hydrogen supply. It is given in cm³ of gas per 100 g of metal, referred to 0 °C and 1,013 mbar. What matters is the jump on solidification: for aluminium the solubility drops by a factor of around 20, for iron only by a factor of about 3.5.

The dissolved amount rises with the hydrogen partial pressure above the melt, namely with its square root (Sieverts' law). Every additional source of hydrogen in the arc therefore increases what the weld pool takes up. For conversion: 1 ppm corresponds to 1.1124 cm³/100 g.

Pure aluminium is the most susceptible to porosity. In the alloys the solubility jump is smaller, so they are less prone to porosity.

Where does the hydrogen in the weld come from?

From four sources: the base metal, the filler metal, the shielding gas and the surroundings. Almost always it is moisture or grease that breaks down in the arc. Often many small weak points add up to a large porosity problem.

Source	How the hydrogen gets into the weld	Remedy
Base material	hydrated oxide layer, grease, dirt, condensation on cold parts	degrease, remove oxide shortly beforehand, let parts acclimatise; Surface preparation (page 44)
Filler material	oxide and moisture on the wire surface, spools stored unprotected	shaved wire, store spools packed and dry, protect opened spools
Shielding gas	moisture in the gas, leaking or damp hoses and connections, air drawn in	leak-tight gas supply, check hoses, choose suitable gas flow and gas nozzle
Surroundings	high humidity, draughts through open hall doors, temperature changes	observe the dew point, avoid draughts; Condensation (page 45)

Also in the full article on migal.co: How do you avoid hydrogen pores · At what hydrogen content do pores form · How do pores affect the weld · What porosity does ISO 10042 permit

Surface treatment.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

DOES ALUMINIUM HAVE TO BE CLEANED BEFORE WELDING?

> Yes, if low-porosity, strong and consistent welds are required. The surface plays a far larger role with aluminium than with steel, because grease, moisture and oxide carry hydrogen and foreign matter straight into the weld pool. Cleaning must therefore follow proven, defined and repeatable procedures.

The sequence is always the same: store correctly, degrease, remove the oxide layer and then weld promptly. Brushing first and degreasing afterwards works the grease into the surface.

A research project on reproducibility in MIG welding of aluminium (AiF 12.239 N, ISF Aachen, University of Hannover and IfS Braunschweig) shows what the individual steps achieve:

- Careful removal of grease and oil at the joint reduced porosity in all tests.
- Removing the oxide immediately before welding did not reduce porosity in every case, but made the results more consistent: tensile strength scattered by ± 1.8 N/mm² for brushed specimens and by ± 6.6 N/mm² for untreated ones.
- Milled joint edges consistently gave better welds than guillotine-sheared edges, because no uneven air gap lets air reach the root.
- Even felt-tip marker lines and fingerprints on the joint disturbed the process.

How do you degrease aluminium before welding?

With a grease-dissolving cleaning agent such as acetone or alcohol and a clean, lint-free cloth, in the area of the joint and the adjacent surfaces. After that, handle the parts only with clean gloves.

Chlorinated solvents do not belong at the welding workplace: under the UV radiation of the arc, toxic gases form from their vapours. The cleaning agent must have evaporated completely before the arc is struck.

In series production, for example in car body manufacturing, joints are also cleaned without liquid chemicals. Methods described include CO_2 snow blasting, which partially removes drawing oil and dry lubricant, and hot active plasma, after which significantly fewer pores occurred on oiled sheets. In laser welding, laser cleaning of the sheets reduced porosity to below 1 %.

How do you remove the oxide layer?

Mechanically with a stainless steel brush, by scraping or milling, and in series production also chemically by pickling. What matters is that as little time as possible passes between oxide removal and welding, because the oxide layer starts growing again immediately.

Method	What matters
Brushing	stainless steel brush with light pressure; too much pressure pushes oxide and dirt into the soft surface. With multi-pass welds, brush every pass.
Milling and scraping	removes oxide together with the surface layer by cutting, without abrasive residues; for bevels and joint preparation, use a milling ring on an angle grinder
Grinding	avoid if possible: abrasive grit and binder can become embedded in the soft aluminium and then end up in the weld
Blasting	only with clean, iron-free blasting media; the effect on porosity is limited
Pickling	for series production and large areas; rinse and dry thoroughly afterwards, otherwise residues and hydrated layers become new sources of hydrogen

Tools for aluminium stay with aluminium. Brushes, files or abrasives previously used on steel carry in iron particles, which can later trigger pitting corrosion.

MIGAL.CO milling rings remove aluminium by cutting on an angle grinder, for bevelling weld edges, levelling welds and opening up the root. No grinding dust is produced and no abrasive residues remain in the material. More under Milling replaces grinding: Milling rings and Double-sided milling rings.

Does the welding wire also have to be cleaned?

Not in production, and you should not try to. The wire surface is created by the manufacturer and must come out clean, uniform and with a thin oxide layer there. For the user, what matters is to preserve this condition until welding.

MIGAL.CO shaves its aluminium wire: the surface is removed together with the oxide and re-forms under defined conditions. The wire is packed gas-tight under vacuum in aluminium composite foil. Why this matters is explained under Oxide layer (page 42). All wires with data sheets: Aluminium welding wire.

Also in the full article on migal.co: How should sheets, profiles and welding wire be stored

Full article on migal.co
migal.co/en/service/welding-of-aluminium/surface-treatment-prior-to-welding

Condensation.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHY IS CONDENSATION A PROBLEM WHEN WELDING ALUMINIUM?

If the metal is colder than the dew point of the surrounding air, water settles on the surface, just as on a cold glass of beer. At a hall temperature of 20 °C and 73 % relative humidity, a temperature difference of only 5 K is enough. The water breaks down into hydrogen in the arc and causes pores in the weld.

Production conditions therefore change with the seasons. A welding procedure that produces pore-free welds in summer can suddenly cause problems in winter or on humid spring days, without anything having changed in the wire, gas or parameters.

At what humidity does water condense on the metal?

The table shows the relative humidity at which water condenses on the metal for a given temperature difference. For other values, use the Dew point calculator.

Metal colder than the air by	Condensation at relative humidity
1 K	ab 94 %
2 K	ab 88 %
3 K	ab 83 %
4 K	ab 78 %
5 K	ab 73 %
6 K	ab 68 %
7 K	ab 64 %
8 K	ab 60 %
10 K	ab 53 %
12 K	ab 46 %
15 K	ab 37 %
20 K	ab 26 %

Calculated using the Magnus formula for an air temperature of 20 °C. With cooler air the values are one to three percentage points lower, with warmer air slightly higher.

Hall air at 50 % humidity, as is usual in winter with heating, therefore tolerates a temperature difference of about 11 K. On a humid summer day at 80 %, 3 to 4 K are enough.

How do you prevent condensation?

By letting material and wire reach the production temperature before they are opened and processed. Where that is not enough, preheating keeps the surface above the dew point.

Situation	Remedy
Goods receipt in winter	store components and wire in the production environment for at least 24 hours; open the wire packaging only after the temperature has equalised
Cold components, little time	preheat until hand-warm, preferably electrically or with hot air; Preheating and interpass temperature (page 52)
Preheating with a flame	the flame itself brings water vapour, around 31 % with propane-oxygen and around 3.6 % with acetylene-oxygen; heat until nothing condenses any more, the surface must be dry before welding
Storage of filler metals	in a heated storage cabinet at 30 to 40 °C
Opened spool	remove it from the machine at the end of work or store it protected in the cabinet; do not leave it overnight in a hall that is cooling down
Change in weather, humid air	measure humidity and component temperature, check the dew point, keep hall doors closed

A simple thermo-hygrometer in the hall and a surface thermometer are enough to assess the risk before the shift starts. The Dew point calculator provides the matching dew point.

MIGAL.CO supplies its shaved aluminium wire in gas-tight vacuum packaging made of aluminium composite foil, the type of packaging that stayed tight in the ISF test. As long as it is closed, no condensation can form on the wire. That is why it pays to open it only at production temperature. All wires with data sheets: Aluminium welding wire.

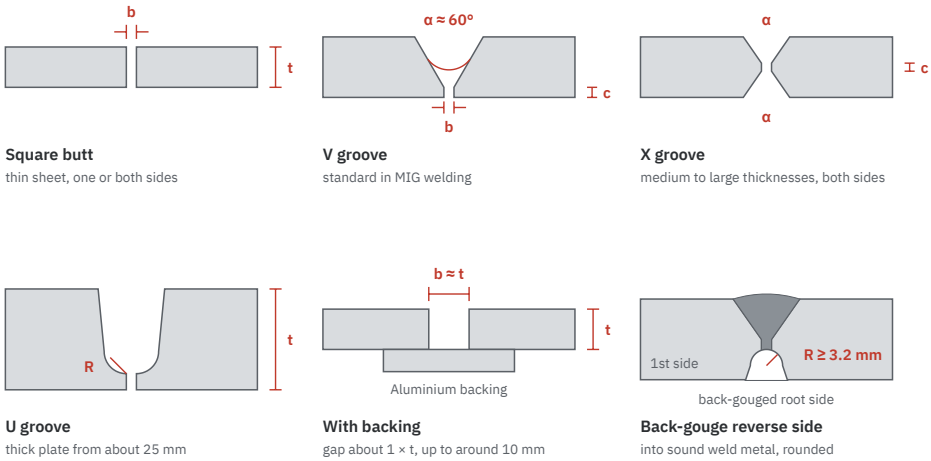
Also in the full article on migal.co: When does condensation form on aluminium · What does condensation do to the wire and the oxide layer

Joint preparation.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHAT IS DIFFERENT ABOUT JOINT PREPARATION FOR ALUMINIUM COMPARED WITH STEEL?

> The joint has to do more. The gas nozzle needs room to reach the root, the edges must be clean and even, and on the root side the oxide layer remains in place because the arc cannot reach it there. That is why included angles and gaps are usually larger for aluminium than for steel.



Schematic, not to scale. t plate thickness, b gap, c root face, α included angle. Dimensions according to EN ISO 9692-3 and the welding procedure specification.

Joint preparations for gas-shielded welding of aluminium

Uneven edges take their toll in particular. In the research project AiF 12.239 N, sheets with milled joint edges consistently gave better welds than sheets that had only been cut with a guillotine shear. In single-sided welding, the uneven air gap let air reach the weld from below.

What the oxide layer is all about is explained under Oxide layer (page 42); how to remove grease and oxide before welding under Surface preparation before welding (page 44).

How do you get a sound root?

In single-sided welding, the oxide layer stays on the root side. It has to be broken through by the weld pool, so the root needs a reliable penetration zone. In welding from both sides, the reverse side is back-gouged down to sound weld metal.

- **Temporary backing:** a backing bar with a groove helps to keep the penetration zone even in MIG welding.
- **Permanent aluminium backing:** the gap must be large enough for the cleaning action of the arc to reach the oxide on the backing, around one plate thickness up to a plate thickness of about 10 mm. The backing lies flush or has a shallow groove and is tacked in place. Projections that protrude into the joint cause lack of fusion.
- **Back-gouging the reverse side:** by cutting with a milling cutter, router or pneumatic chisel. The bottom of the groove needs a radius of at least 3.2 mm. Sharp chisel notches and saw cuts cannot be reliably fused at their bottom.

Double-sided milling rings on an angle grinder are suitable for back-gouging and for removing fillet welds, see Double-sided milling rings.

Also in the full article on migal.co: Which joint type for which plate thickness · How do you cut and machine aluminium for welding · How do you tack and clamp aluminium correctly · Which brush and which blasting media

Full article on migal.co
migal.co/en/service/welding-of-aluminium/joint-preparation

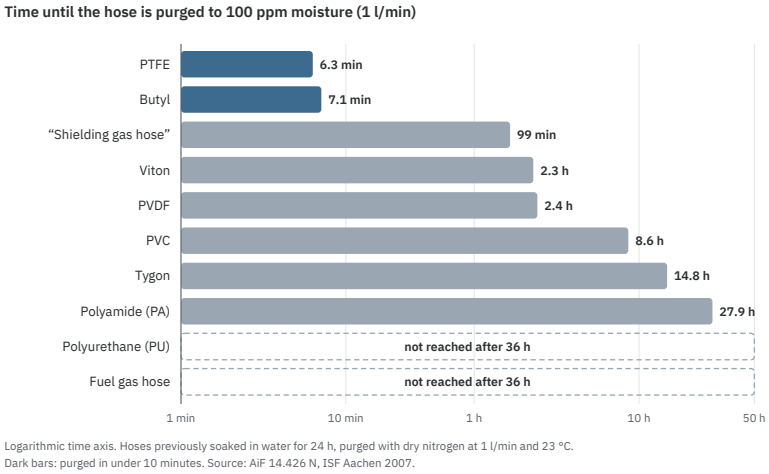
Application notes › Aluminium

Gas-shielded welding.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHICH GAS SHIELDED PROCESSES ARE USED FOR ALUMINIUM?

Mainly MIG welding and TIG welding. Both work with an inert shielding gas, that is argon, helium or a mixture of the two. Measured by the amount of filler metal deposited, aluminium is predominantly MIG welded.



Purging time of gas hoses down to 100 ppm moisture

	MIG	TIG
Electrode	the welding wire itself, it melts off	tungsten, does not melt off; filler metal is fed separately
Power source	constant voltage, usually pulsed arc	constant current, usually alternating current for aluminium
Deposition rate	high	low
Mechanisation	very good, standard on robots	limited
Typical use	vehicle, ship, steel and plant construction, series production	tank and apparatus construction, pipes, root passes, thin sheet

For sheet under 2 mm, TIG welding was long the default. With the pulsed arc, thin sheet can now also be MIG welded reliably, and the MIG process is increasingly taking over this range. In AC TIG welding the positive half-wave breaks up the oxide layer. Why this is necessary is explained under Oxide layer (page 42).

Which shielding gas is needed for aluminium?

An inert gas: argon, helium or an argon-helium mixture. Mixed gases for steel containing CO_2 or significant oxygen are unsuitable for aluminium, as they oxidise the weld pool. The gases are classified in ISO 14175.

Group to ISO 14175	Composition	Used for
I1	Argon	standard gas for MIG and TIG, calm arc, easy ignition
I3	Argon with helium, e.g. ArHe 30 (30 % helium)	thicker sheet, fillet welds, higher welding speed
I2	Helium	special cases, such as DC TIG welding of thick parts
Z	Argon or argon-helium with additions in the ppm range, such as oxygen or nitrogen	manufacturers’ gases for specific applications; according to EN 1011-4 only if specified by the design

For group I gases, the standard requires a purity of at least 99.99 % and no more than 40 ppm moisture, corresponding to a dew point of −50 °C. These values apply to the gas in the cylinder or tank. What arrives at the torch is decided by the gas supply line (see below).

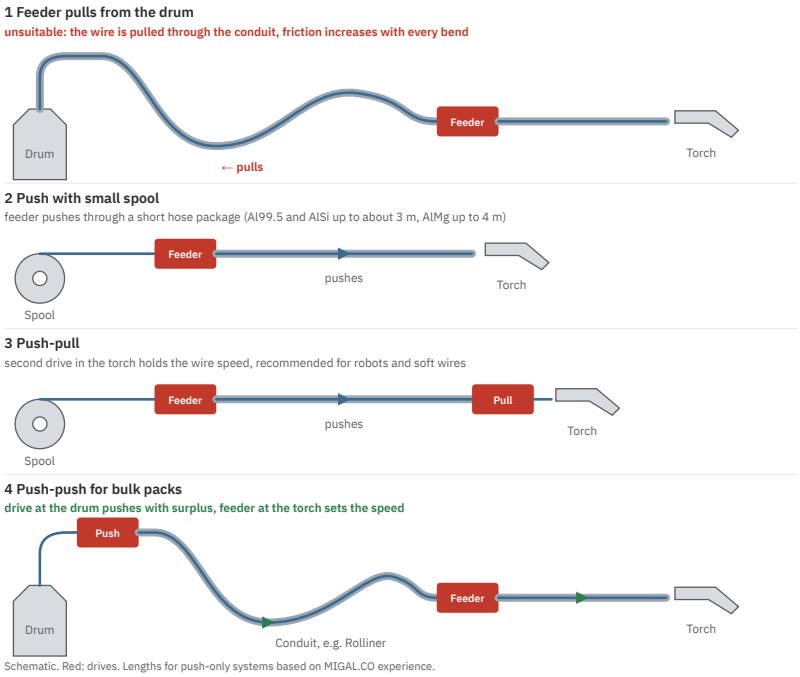
Also in the full article on migal.co: What does helium add to the shielding gas · How much shielding gas is needed when welding aluminium · How dry must the shielding gas be at the torch · What disturbs the gas shield in practice · Which filler metal and which wire feeding

Wire feeding.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHY IS ALUMINIUM WIRE HARDER TO FEED THAN STEEL WIRE?

Because it is soft and buckles easily. Wire feed systems were developed for steel wire, which is stiff and slides well. Aluminium wire has a much lower buckling stiffness, deforms under the pressure of the feed rolls and is shaved off at every sharp edge.



Wire feeding systems for aluminium

Pure aluminium and the AlSi wires are the most difficult, because they are softer than the AlMg wires. Yet a constant wire speed is one of the most important variables in MIG welding. If it fluctuates, arc length, penetration and weld shape fluctuate too. In the research project AiF 12.239 N, roll pressure, brake, contamination and routing of the hose package had a “decisive influence” on the result. After every change to the feed system, the process had to be set up again.

Which wire feed system is suitable for aluminium?

One in which the wire is only pushed over short distances and never pulled through a long hose. The softer the wire and the longer the path, the more likely you need a second drive.

System	Use
Push, small spool	manual welding with a short hose package: for Al99.5 and AlSi no more than about 3 m, for AlMg up to 4 m
Push-pull	second drive in the torch; for soft wires, longer hose packages and for robots and automated systems, there with hose packages of 1.5 to 2 m
Push-push	for drums and large spools: a drive at the pack pushes the wire with surplus into the conduit, the feeder at the torch sets the speed

How important the second drive can be is shown by AiF 12.239 N: with a push-pull torch, operating with the rear drive only no longer produced usable welds. A hose package bent by up to about 180°, by contrast, had no effect on the weld in the same trial.

Also in the full article on migal.co: Why must aluminium wire not be pulled through a liner · What matters with feed rolls, liner and contact tip · How do you feed aluminium wire from a drum

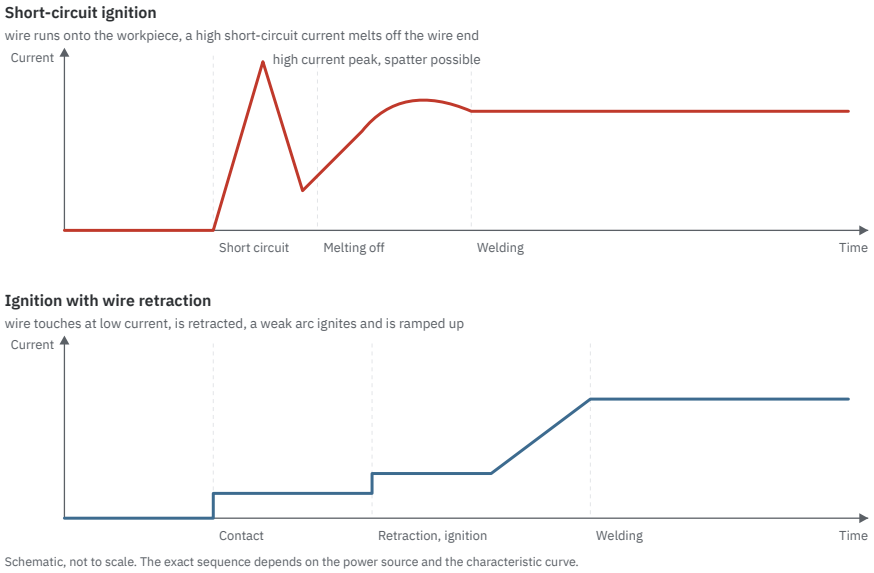
Full article on migal.co
migal.co/en/service/welding-of-aluminium/wire-feeding

Arc ignition.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHY DOES THE ARC IGNITE LESS EASILY ON ALUMINIUM THAN ON STEEL?

Because aluminium conducts electricity very well and is covered with an insulating oxide layer. In short-circuit ignition, the wire end has to heat up so much that it melts off and ionises the shielding gas. With aluminium, far less resistance heating is produced than with steel.



Sequence of arc ignition in MIG welding

- **Conductivity:** the heat in the wire end is generated by the current in the electrical resistance ($I^2 \cdot R$). Aluminium conducts many times better than steel, so the wire end heats up more slowly. The purer the wire, the higher the conductivity and the more difficult the ignition.
- **Oxide layer:** the wire end and the workpiece carry a hard, electrically insulating oxide layer. It must be broken through before current can flow. Thick layers after heat treatment, damp storage or anodising prevent ignition altogether.
- **Heat conduction:** aluminium conducts heat away quickly. On a cold workpiece the weld start therefore fuses less well than on steel.
- **Shielding gas:** helium is harder to ionise than argon. As the helium content increases, ignition becomes more difficult.

More on the oxide layer under Oxide layer (page 42), more on argon and helium under Gas shielded welding (page 47).

How does a MIG power source ignite the arc?

Almost always by short circuit: the wire runs onto the workpiece, a high current melts off the wire end, and the arc is established. How well this works with aluminium depends on how quickly the power source can control the current.

Ignition method	How it works
Conventional short-circuit ignition	The current rise is set by means of inductors. With aluminium this often solved the ignition problem only partly.
Electronically controlled ignition	Modern power sources let the ignition current rise very quickly and then return rapidly to the welding parameters.
Ignition with wire retraction	The wire moves slowly until contact, is retracted a few millimetres, and a low-power arc ignites. It is then quickly brought to the welding parameters. Ignition is practically spatter-free and precisely timed.

Ignition with wire retraction needs a wire drive directly at the torch that moves the wire forwards and backwards precisely. This makes the torch larger and heavier, which is a drawback in manual welding and on robots. How drives at the torch work is described under Wire feeding (page 48).

Also in the full article on migal.co: What disturbs ignition in practice · How do you avoid defects at the weld start · How do you ignite when TIG welding aluminium

Weld start and end crater.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHY ARE THE START AND END OF THE WELD CRITICAL WITH ALUMINIUM?

> Because aluminium conducts heat away very quickly. At the start of the weld the workpiece is still cold, and the arc fuses the base metal poorly. During welding the heat then runs ahead so rapidly that unfavourable conditions for clean crater filling arise at the end of the weld.

- **At the weld start** there is a risk of lack of fusion and porosity, because the molten metal meets cold material. The weld start is also the point at which aluminium forms hot cracks most easily. This was shown by the research project AiF 13.983 at the University of Magdeburg.
- **At the weld end** a crater remains if the arc goes out abruptly. Aluminium shrinks by about 6 % of its volume on solidification. If there is not enough molten metal in the crater, shrinkage cavities and crater cracks form. In the same project, the cracks in specimens welded without filler metal were found particularly in the end crater.

How to ignite the arc reliably is covered under Arc ignition (page 49).

What do current programmes achieve for the weld start and end crater?

They improve both, but do not reliably eliminate the defects. Modern power sources run an increased start current at the weld start and reduce to a crater fill current at the end of the weld before switching off.

A typical programme starts at about 150 % of the welding current, changes to 100 % after a short time and ends at about 50 % to fill the crater. The exact values and times belong in the welding procedure specification and are tested on the component. EN 1011-4 explicitly names the crater fill programme as a remedy against crater cracks.

The limit in MIG welding: with synergic characteristics, the wire feed is tied to the current. More power at the weld start also means more wire, less power at the weld end less wire. What would be needed is exactly the opposite: plenty of heat with little wire at the start, enough wire to fill with little heat at the end. That is why lack of fusion at the start, porosity and crater cracks cannot be reliably avoided with current programmes alone.

How do you fill the end crater manually?

Do not simply break off the arc. At the end of the weld, stop travelling briefly and fill the crater before it solidifies, then end the arc.

- **TIG with remote or foot control:** reduce the current slowly while adding filler metal until the pool solidifies.
- **Without current reduction:** at the end, quickly lead the arc back a short way onto the finished weld while speeding up, so that the weld tapers off over a short distance and the crater stays small.
- **Mechanised:** programme wire feed, current and voltage so that the crater is filled on stopping and the values are gradually reduced.

This is also how the AWS Welding Handbook describes it. A crater crack cannot be repaired afterwards by welding over it: it must be ground or milled out and rewelded.

How cracks can be avoided in general and which filler metal reduces the cracking tendency is shown under Weld defects and how to avoid them (page 54).

Black deposit

What is the black deposit beside the weld?

Mainly magnesium oxide. Magnesium evaporates in the arc, oxidises at the edge of the gas shield and settles as a dark band beside the weld. It has nothing to do with soot or combustion residues.

Magnesium oxide is usually known as a white powder. Depending on how it forms and how thick the layer is, however, it can also look grey, yellow, brown or black. In a doctoral thesis at TU Berlin (Goecke, 2004), EDS analysis of the deposit showed, besides aluminium, around 50 to 60 % oxygen and 30 to 40 % magnesium. On each side the band extended about twice as far as the weld was wide.

The deposit does not affect the strength of the weld. It is a nuisance, however, wherever the surface has to be clean, for example on pallets for the chemical and food industries, on ladders and scaffolding, or before painting and anodising. It is easy to brush off, but in places that are hard to reach this means additional manual work.

Also in the full article on migal.co: How can the black deposit be reduced · Which additional measures help · Why does the deposit occur mainly with AlMg alloys

Full article on migal.co
migal.co/en/service/welding-of-aluminium/melting-end-crater

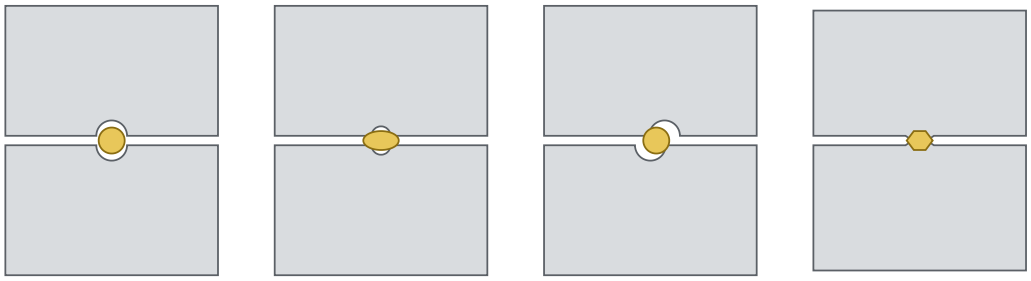
Special points.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

HOW DO YOU CHECK A MIG SYSTEM FOR ALUMINIUM?

Along the wire path, from the spool to the contact tip. Most problems in aluminium welding do not arise in the arc, but because the soft wire scrapes, jams or picks up dirt somewhere.

Cross-section through the pair of rolls, wire in yellow. Schematic, not to scale.



✓ **1 Correct**
groove fits, rolls aligned

✗ **2 Groove too small**
wire is squashed

✗ **3 Rolls offset**
wire is scraped sideways

✗ **4 Knurled or V-groove**
soft wire gets notched

Feed rolls for aluminium wire

Check point	What matters
Inlet guides and guide tubes	precisely aligned with the rolls, wide enough, free of burrs; the wire must not run over hard or metallic edges anywhere
Feed rolls	designed by the manufacturer for aluminium, usually with a half-round groove; grooves matching the wire diameter and exactly aligned
Roll pressure	as low as possible; never increase the pressure when feeding problems occur, but look for the cause
Contact tip	bore about 0.35 to 0.4 mm larger than the wire; contact tips for steel are bored only about 0.15 to 0.2 mm larger
Friction in the system	with the pressure levers open, it must be possible to push the wire through the whole system with two fingers and moderate force; the motor current of the wire feeder should be barely above the no-load value and should be monitored regularly
Cleanliness	keep all parts in contact with the wire clean, no lubricants and no anti-spatter spray; always cover wire spools and protect them from dust and moisture
Gas hoses	replace them if they have been mixed up with water hoses, because they can no longer be dried completely; choose diffusion-tight materials and short lines
Arc length	as short as possible; too long an arc draws in air and causes porosity and oxide inclusions

More detail: Wire feeding (page 48), Gas shielded welding (page 47) and Arc ignition (page 49).

What is special about TIG welding aluminium?

The filler rod is fed by hand and is exposed to the air for much longer than a MIG wire. Cleanliness and dry storage of the rods are therefore particularly important.

- Always reseal opened packs and protect them from moisture and dust. Take out only as many rods as will be needed in the next few hours.
- Do not handle rods with bare hands. Gloves must be dry and free of grease. Wipe dirty rods with acetone and a clean, lint-free cloth immediately before welding.
- Keep the hot rod end in the shielding gas until it has cooled. Otherwise it oxidises, and the oxide gets into the weld the next time the rod is applied.
- The same applies to gas hoses and gas shielding as in MIG welding.

Also in the full article on migal.co: Can aluminium castings and die castings be welded · Can aluminium be welded to steel

Preheating.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

DOES ALUMINIUM NEED TO BE PREHEATED BEFORE WELDING?

> Usually not. Aluminium does not harden and does not suffer hydrogen-induced cold cracking like steel, so there is no minimum preheat temperature. Preheating is used for specific purposes: to remove moisture, to improve the cold start, to balance large differences in thickness or to slow down cooling on thick parts. For aluminium, maximum values apply, because too much heat costs strength.

This is the most important difference from steel. There you calculate how hot a component must be at least, for example with the preheat temperature calculator according to EN 1011-2. For aluminium, EN 1011-4 specifies how hot it may get at most.

When is preheating aluminium useful?

EN 1011-4 gives four reasons: removing moisture before welding, for example on site; avoiding imperfections at a cold start; balancing the heat where very different thicknesses are joined; and moderating the cooling rate when welding thick parts.

- **Moisture:** cold parts mist over in warm workshop air. Brief warming dries the joint, see Condensation (page 45). According to the ASM handbook, brief heating to no more than 120 °C is enough for this.
- **Cold start:** aluminium conducts heat around three times as well as steel. At the cold start of the weld the heat flows away so quickly that lack of fusion occurs and the gas has too little time to escape. Against porosity, too, the standard therefore recommends more heat input or preheating.
- **Differences in thickness:** the thick part draws the heat away, the thin part overheats. Preheating the thick part compensates for this. A practical rule of thumb is a wall thickness ratio of no more than 1:3.
- **Thick parts:** on large cross-sections, preheating slows down the rapid cooling that would otherwise lead to lack of fusion and porosity.

Preheating can often be avoided altogether. According to EN 1011-4, a shielding gas of argon and helium or pure helium can replace the preheating that would otherwise be needed, because helium brings the heat into the workpiece more effectively; more on this under Gas shielded welding (page 47).

Why does too much heat cost strength?

Because the heat-affected zone beside the weld loses its strength condition. Work-hardened alloys become soft, heat-treated alloys over-age. Every degree of preheat and every interpass that is too hot widens this zone.

- **Non-heat-treatable, work-hardened alloys** such as 5083-H lose their work hardening after just a few seconds above 345 °C, according to the ASM handbook over 25 to 38 mm beside the weld. Welded in the soft O temper, by contrast, they retain almost their full load-bearing capacity: in a study on 13 mm thick 5083-O, the MIG weld reached a tensile strength of 308 MPa, the base metal around 333 MPa.
- **Heat-treatable alloys** such as 6082-T6 over-age in the heat-affected zone, fastest between 290 and 425 °C. In the same study, MIG welds on 6082-T6 reached only 232 MPa instead of around 300 MPa, and the fracture was in the heat-affected zone. Preheating, not cooling between runs and slow weaving reduce this value further, until a procedure qualification may fail.

The weld itself reacts too. In the research project AiF 12.239 N, a backing heated to 40 °C made no difference. At 85 °C the welds became wider and the penetration deeper, with a tendency to burn through. Anyone who preheats has to adjust the parameters accordingly.

More on the differences between the alloy groups and on the choice of filler metal: Differences from steel (page 41).

Also in the full article on migal.co: How high may the preheat and interpass temperature be · How do you preheat correctly and how do you measure

Full article on migal.co
migal.co/en/service/welding-of-aluminium

Anodising.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHY DOES THE WELD BECOME DISCOLOURED WHEN ANODISED?

Because the anodic layer grows out of the metal itself, and its alloying elements determine the colour. If the weld metal has a different composition from the base metal, the weld shows up clearly after anodising.

- **Silicon** colours grey to black, the more strongly the more silicon there is in the weld metal. EN 1011-4 states that AlSi fillers do not give a good colour match with wrought alloys. Welds made with AlSi5 turn dark to black after anodising.
- **Chromium** gives a yellowish to golden tint.
- **Manganese** discolours, in our experience, slightly yellowish; the ASM Specialty Handbook Aluminum describes a faint grey instead.
- **Magnesium** and pure aluminium anodise light and match most wrought alloys best.

Even with a suitable filler, the heat-affected zone can show up, because the heat of welding has changed the microstructure there. For colour-critical parts, therefore, always weld a test piece and anodise it using the same process.

Which filler metal is suitable for anodised components?

One whose composition is as close as possible to that of the base metal. AlMg and pure aluminium fillers are particularly suitable for anodising; AlSi fillers are not.

Base material	Filler for a good colour match
Pure aluminium, AlMn1, AlMg1	MA-1070 Al99,7 or MA-1450 Al99,5Ti
AlMg2,5, AlMg3	AlMg3
AlMg4,5Mn, AlMg3Mn, AlMg5	MA-5183 AlMg4,5Mn0,7 or MA-5556 AlMg5Mn
AlMgSi (z. B. 6060, 6063, 6082)	MA-5356 AlMg5Cr or MA-5556 AlMg5Mn , not AlSi5; see the trade-off below
AlSi casting alloys	AlSi filler; casting and weld anodise grey in any case

Compiled from EN 1011-4, Annex B, and the ASM Specialty Handbook Aluminum. Trials with the actual anodising process are what count.

EN 1011-4 recommends matching the magnesium content of the filler to that of the base metal when colour match and corrosion resistance are decisive. If high weld metal strength is required, however, a filler with 4.5 to 5 % magnesium is chosen. The batch of filler metal can also influence the shade. For colour-critical applications, the batch used should be tested before production. All wires with data sheets: Aluminium welding wire.

What applies to AlMgSi alloys (6000 series)?

There is a trade-off here. AlSi fillers protect AlMgSi alloys best against hot cracking but turn dark when anodised. AlMg fillers match better in colour but require more care to avoid cracks.

The alloys of the 6000 series lie close to the maximum of hot cracking sensitivity. They cannot be welded crack-free without filler or with matching filler. In the research project AiF 13.983 at the University of Magdeburg, welds made with AlSi filler were considerably more crack-resistant. For decoratively anodised parts, for example in rail vehicle construction, AlSi5 and AlSi12 are unsuitable, however.

Anyone who wants to anodise AlMgSi therefore usually welds with AlMg5 and uses a gap or bevel to get enough filler into the weld metal. How to do this is described in Joint preparation (page 46).

MA-6063 AlMg0,7SiTiB takes a new approach: a near-matching filler for 6000 series alloys. Titanium-boron particles refine the grain structure and so reduce hot cracking sensitivity. Whether the weld anodises to the same colour in a given case should be checked on a test piece.

Can parts that are already anodised be welded?

Yes, but only after removing the anodic layer in the weld area. The layer is hard, melts far above aluminium and is electrically insulating.

- Remove the anodic layer mechanically at the joint and at the ground connection, for example by milling or scraping. Otherwise the arc ignites poorly, and lack of fusion and oxide inclusions are likely.
- After welding, the protection in the weld area is interrupted. The weld must be anodised again or protected in another way.

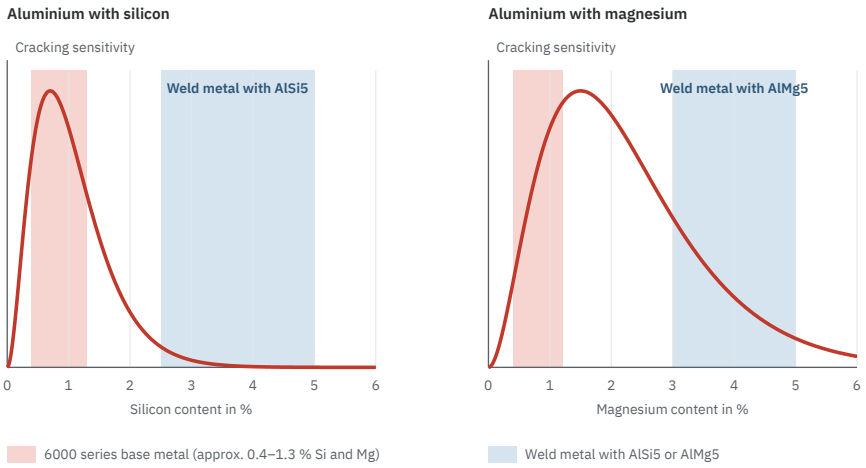
More under Oxide layer (page 42) and Arc ignition (page 49).

Avoiding weld defects.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHICH WELD DEFECTS ARE TYPICAL OF ALUMINIUM?

Above all porosity, oxide inclusions with lack of fusion, and hot cracks. All three are caused by properties of aluminium: hydrogen, the tenacious oxide layer and the high solidification shrinkage.



Schematic, based on published data (AiF 13.983, ASM Specialty Handbook Aluminum). Peak positions vary by alloy system.

Hot cracking susceptibility as a function of silicon and magnesium content

Defect	Main cause	More on this
Porosity	hydrogen from moisture, dirt and hydrated oxide that cannot escape during solidification	Solubility of hydrogen (page 43)
Oxide inclusions, lack of fusion	oxide that melts only at around 2,050 °C and was not broken up or not removed	Oxide layer (page 42)
Hot cracking	weld metal composition close to the maximum cracking sensitivity, high shrinkage and stresses	section below
Tungsten and copper inclusions	current too high, electrode dipping into the pool, overheated contact tip, copper backing	section below

The tables on this page essentially follow EN 1011-4, Annex A. The standard stresses that these defects are to be avoided above all in dynamically loaded and safety-relevant components.

Why does aluminium crack during welding?

Because many aluminium alloys lie in a composition range in which the weld metal cracks particularly easily during solidification. Cracking sensitivity is greatest at about 0.5 to 1 % silicon and at about 1.5 % magnesium. A filler metal with a considerably higher alloy content takes the weld metal out of this range.

On solidifying, aluminium shrinks by around 6 % of its volume. Between the grains that are already solid there is still liquid residual melt. If it is not enough to compensate for the shrinkage, the structure tears open. Such solidification cracks usually lie in the weld centre, in the end crater and at the weld start.

With their silicon and magnesium contents, the 6000 series alloys (AlMgSi) lie exactly in the critical ranges. They therefore cannot be welded crack-free without filler or with matching filler without grain refinement. In the research project AiF 13.983 at the University of Magdeburg, this was not achieved in TIG specimens of 6082 without filler, even with sheets more than 300 mm wide.

Also in the full article on migal.co: Which filler metal reduces cracking sensitivity · How do you avoid porosity when welding aluminium · Where do oxide inclusions and lack of fusion come from · What are liquation cracks in the heat-affected zone · How do you avoid cracks at the weld start and in the end crater · How do tungsten and copper inclusions arise

Welding rods, wire electrodes and brazing wires

Copper alloys.

11 copper-based alloys: as wire electrodes for MIG welding and arc brazing and as rods for TIG welding. The bronze wires join and clad copper materials and steels; CuSi3 and CuAl8 are the usual brazing filler metals for galvanised thin sheet.

ML CuAl8	S Cu 6100	56
ML CuAl8Ni2	S Cu 6327	57
ML CuAl8Ni6	S Cu 6328	58
ML CuAl9Fe	S Cu 6180	59
ML CuMn13Al7	S Cu 6338	60
ML CuNi10Fe	S Cu 7061	61
ML CuNi30Fe	S Cu 7158	62
ML CuSi28L	S Cu 6560	63
ML CuSi3	S Cu 6560	64
ML CuSn	S Cu 1898A	65
ML CuSn6	S Cu 5180A	66

Copper

Application notes. Processes, brazing filler metals, shielding gas, joint types and weld defects: notes on arc brazing from page 67.

Copper alloys › Data sheet

ML CuAl8.

Copper alloy welding rod/wire electrode

Typical composition of the filler metal in %

Al	Si	Mn	Zn	Pb	Others total
6,00–8,50	< 0,20	< 0,50	< 0,20	< 0,02	< 0,40

Classification

ISO 24373	S Cu 6100 (CuAl7)
DIN 1733	SG-CuAl8
Material no.	2.0921
BS 2901 part 3	C 28
AWS A 5.7	ER Cu Al-A1

Base materials

CuAl5; CuAl8; CuAl9; CuZn20Al

Notes

Filler metal for joining and surfacing of Al-bronze, brass, steel- and cast-iron, as well as for MIG-brazing of carbon-steel with and without coating. Suitable for joining of steel to copper. The weld metal is resistant to corrosion, wear and brackish water.

Application notes from page 67.

Properties approx. values

Electrical conductivity [S·m/mm²]	8
Density [kg/dm³]	7,7
Solidus-Temperature [°C]	1030
Liquidus-Temperature [°C]	1040
Tensile strength R_m [MPa]	390–450
Elongation A_5 (L_0 = 5 d_0) [%]	45
Hardness [HB]	140

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (Argon, Helium or Argon-Helium-mixtures)
Polarity	MIG = +, TIG ~

Dimensions and packaging

MIG wire Ø [mm] 0,8 1,0 1,2 1,6

TIG rod Ø [mm] 1,6 2,0 2,4 3,2 4,0

Wire electrodes	Packaging unit
S 200 / 5 kg	–
S 300 / 15 kg	25 spools = 375 kg (Pallet)
B 300 / BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Drums	Packaging unit
ECO-drum / 200 kg	2 drums = 400 kg (Pallet)
JUMBO-drum / 200 kg	2 drums = 400 kg (Pallet)

Current data sheet and stock level
migal.co/en/products/copper-welding-and-brazing-wire/ml-cual8

Copper alloys › Data sheet

ML CuAl8Ni2.

Copper alloy welding rod/wire electrode

Typical composition of the filler metal in %

Al	Si	Mn	Ni incl. Co	Zn	Pb	Fe	Others total
7,00–9,50	< 0,20	0,50–2,50	0,50–3,00	< 0,20	< 0,02	0,50–2,50	< 0,40

Classification

ISO 24373	S Cu 6327 (CuAl8Ni2Fe2Mn2)
DIN 1733	SG-CuAl8Ni2
Material no.	2.0922
BS 2901 part 3	C 29

Base materials

CuAl10Ni; CuAl11Ni; Copper-Aluminium-Nickel alloys in general

Notes

Filler metal for Cu-Al-Ni-materials and for joining steel to Cu-Al alloys. Surfacing of Al-bronzes and aluminium coated steels. Can be used for cast-iron in mechanical engineering, shipbuilding and chemical industry. Excellent sea water restistance (i.e. surfacing of ship's propellors) MIG pulse welding is recommended for multi-pass surfacing welds on steel.

Application notes from page 67.

Properties approx. values

Electrical conductivity [S·m/mm²]	5
Density [kg/dm³]	7,5
Solidus-Temperature [°C]	1030
Liquidus-Temperature [°C]	1040
Tensile strength R_m [MPa]	430–540
Elongation A_5 (L_0 = 5 d_0) [%]	30
Hardness [HB]	130–150

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (Argon, Helium or Argon-Helium-mixtures)
Polarity	MIG = +, TIG ~

Dimensions and packaging

MIG wire Ø [mm]: 1,0 | 1,2 | 1,6

Wire electrodes	Packaging unit
B 300 / BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Drums	Packaging unit
ECO-drum / 200 kg	2 drums = 400 kg (Pallet)
JUMBO-drum / 200 kg	2 drums = 400 kg (Pallet)

Copper alloys › Data sheet

ML CuAl8Ni6.

Copper alloy welding rod/wire electrode

Typical composition of the filler metal in %

Al	Si	Mn	Ni incl. Co	Zn	Pb	Fe	Others total
8,50–9,50	< 0,10	0,60–3,50	4,00–5,50	< 0,10	< 0,02	3,00–5,00	< 0,50

Classification

ISO 24373	S Cu 6328 (CuAl9Ni5Fe3Mn2)
DIN 1733	SG-CuAl8Ni6
Material no.	2.0923
BS 2901 part 3	C 26 Ni
AWS A 5.7	ER CuNiAl

Base materials

CuAl11Ni6Fe5; CuAl10Ni5Fe4; Copper-Aluminium-Nickel alloys in general

Notes

Filler metal for Cu-Al-Ni-materials and for castings and forged parts from Nickel-Aluminium bronzes. Surfacing of Al-bronzes and aluminium coated steels, and complex bronzes. Excellent sea water restistance (i.e. surfacing of ship's propellors). High wear and abrasion resistance. Suitable for bearings, valves, turbines, pumps etc.

Application notes from page 67.

Properties approx. values

Electrical conductivity [S·m/mm²]	4
Density [kg/dm³]	7,5
Solidus-Temperature [°C]	1015
Liquidus-Temperature [°C]	1045
Tensile strength R_m [MPa]	450–560
Elongation A_5 (L_0 = 5 d_0) [%]	10
Hardness [HB]	150–170

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (Argon, Helium or Argon-Helium-mixtures)
Polarity	MIG = +, TIG ~

Dimensions and packaging

MIG wire Ø [mm]	1,2	1,6

Wire electrodes	Packaging unit
B 300 / BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Current data sheet and stock level
migal.co/en/products/copper-welding-and-brazing-wire/ml-cual8ni6

ML CuAl9Fe.

Copper alloy welding rod/wire electrode

Typical composition of the filler metal in %

Al	Si	Zn	Pb	Fe	Others total
8,50–11,00	< 0,10	< 0,02	< 0,02	< 1,50	< 0,50

Classification

ISO 24373	S Cu 6180 (CuAl10Fe)
Material no.	2.0937
BS 2901 part 3	C 13
AWS A 5.7	ER Cu Al-A2

Base materials

CuAl8Fe3

Notes

Filler wire for joining and surfacing of base metals with similar composition, Manganese-Silicon-bronzes and some Copper-Nickel-alloys. Suitable for joning of steel to Copper. The weld metal is sea water resistant. Very well suitable for flame spraying.

Application notes from page 67.

Properties approx. values

Electrical conductivity [S·m/mm²]	8
Density [kg/dm³]	7,7
Solidus-Temperature [°C]	1030
Liquidus-Temperature [°C]	1040
Tensile strength R_m [MPa]	390–500
Elongation A_5 (L_0 = 5 d_0) [%]	35
Hardness [HB]	140–160

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (Argon, Helium or Argon-Helium-mixtures)
Polarity	MIG = +, TIG ~

Dimensions and packaging

MIG wire Ø [mm]: 0,8 | 1,0 | 1,2 | 1,6

TIG rod Ø [mm]: 1,6 | 2,0 | 2,4 | 3,2 | 4,0

Wire electrodes	Packaging unit
S 200 / 5 kg	–
S 300 / 15 kg	25 spools = 375 kg (Pallet)
B 300 / BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Drums	Packaging unit
ECO-drum / 200 kg	2 drums = 400 kg (Pallet)
JUMBO-drum / 200 kg	2 drums = 400 kg (Pallet)

Copper alloys › Data sheet

ML CuMn13Al7.

Copper alloy welding rod/wire electrode

Typical composition of the filler metal in %

Al	Si	Mn	Ni incl. Co	Zn	Pb	Fe	Others total
7,00–8,50	< 0,10	11,00–14,00	1,50–3,00	< 0,15	< 0,02	2,00–4,00	< 0,50

Classification

ISO 24373	S Cu 6338 (CuMn13Al8Fe3Ni2)
DIN 1733	SG-CuMn13Al7
Material no.	2.1367
BS 2901 part 3	C 22
AWS A 5.7	ER CuMnNiAl

Base materials

Seawater resistant, CuAl-alloys without Zinc of high hardness and strength.

Notes

ML CuMn13Al7 is a Manganese-Nickel-Aluminium bronze for se water resistant joint welds, particularly with erosion, corrosion and cavitation. Suitable for surfacing of Cu-alloys, Carbon-Manganese steels and cast-iron.

Application notes from page 67.

Properties approx. values

Electrical conductivity [S·m/mm²]	3–5
Density [kg/dm³]	7,4
Solidus-Temperature [°C]	945
Liquidus-Temperature [°C]	985
Tensile strength R_m [MPa]	800–900
Elongation A_5 (L_0 = 5 d_0) [%]	10
Hardness [HB]	180–240

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (Argon, Helium or Argon-Helium-mixtures)
Polarity	MIG = +, TIG ~

Dimensions and packaging

MIG wire Ø [mm]: 0,8 | 1,0 | 1,2 | 1,6

TIG rod Ø [mm]: 1,6 | 2,0 | 2,4 | 3,2 | 4,0

Wire electrodes	Packaging unit
B 300 / BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Current data sheet and stock level
migal.co/en/products/copper-welding-and-brazing-wire/ml-cumn13al7

ML CuNi10Fe.

Copper alloy welding rod/wire electrode

Typical composition of the filler metal in %

Ni	Fe	C	Mn	Si	Ti	Al	S	P	Pb	Others total
9,0–11,0	0,5–2,0	< 0,03	0,5–1,5	< 0,2	0,2–0,5	< 0,03	< 0,02	< 0,007	< 0,02	< 0,4

Classification

ISO 24373	S Cu 7061 (CuNi10)
DIN 1733	SG-CuNi10Fe
Material no.	2.0873
BS 2901 part 3	C 16

Base materials

Particularly suitable for highly stressed corrosion resistant weld surfacing on cast iron and on unalloyed and low-alloyed steel, seawater resistant CuZn alloys. Appropriate to joining/surfacing on Cu-Ni material. Especially recommended for plant engineering.

Application notes from page 67.

Properties approx. values

Electrical conductivity [S·m/mm²]	5
Therm. conductivity [W/m K]	45
Density [kg/dm³]	8,9
Melting temperature [°C]	1.150
Tensile strength R_m [MPa]	300
Elongation A_5 (L_0 = 5 d_0) [%]	40
Modulus of elasticity [MPa]	126.000

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (Argon, Helium or Argon-Helium-mixtures)
Polarity	MIG = +, TIG = –

Dimensions and packaging

MIG wire Ø [mm]: 0,8 | 1,0 | 1,2 | 1,6

TIG rod Ø [mm]: 1,6 | 2,0 | 2,4 | 3,2 | 4,0

Wire electrodes	Packaging unit
B 300 / BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Copper alloys › Data sheet

ML CuNi30Fe.

Copper alloy welding rod/wire electrode

Typical composition of the filler metal in %

Ni	Fe	C	Mn	Si	Ti	S	P	Pb	Others total
29,0–32,0	0,4–1,0	< 0,05	0,5–1,5	< 0,2	0,2–0,5	< 0,015	< 0,02	< 0,02	< 0,5

Classification

ISO 24373	S Cu 7158 (CuNi30Mn1FeTi)
DIN 1733	SG-CuNi30Fe
Material no.	2.0837
AWS A 5.7	ER CuNi
BS 2901 part 3	C 18

Base materials

Particularly suitable for high stressed corrosion resistant weld surfacing on cast iron and on unalloyed and low-alloyed steel as well as seawater resistant CuZn alloys. Suitable for welding on CuNi materials. Particularly recommended for the plant engineering.

Application notes from page 67.

Properties approx. values

Electrical conductivity [S·m/mm²]	2
Therm. conductivity [W/m K]	30
Density [kg/dm³]	8,9
Melting temperature [°C]	1.210
Tensile strength R_m [MPa]	400
Elongation A_5 (L_0 = 5 d_0) [%]	35

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (Argon, Helium or Argon-Helium-mixtures)
Polarity	MIG = +, TIG = –

Dimensions and packaging

MIG wire Ø [mm] 0,8 1,0 1,2 1,6

TIG rod Ø [mm] 1,6 2,0 2,4 3,2 4,0

Wire electrodes	Packaging unit
B 300 / BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Current data sheet and stock level
migal.co/en/products/copper-welding-and-brazing-wire/ml-cuni30fe

ML CuSi28L.

Copper alloy welding rod/wire electrode

Typical composition of the filler metal in %

Al	Si	Mn	Sn	Zn	Pb	Fe	Ni	P	Others total
< 0,02	2,80–2,95	0,75–0,95	< 0,05	< 0,10	< 0,01	< 0,10	< 0,05	< 0,05	< 0,50

Classification

ISO 24373	S Cu 6560 (CuSi3Mn1)
DIN 1733	SG-CuSi3
Material no.	2.1461
BS 2901 part 3	C 9
AWS A 5.7	ER Cu Si - A

Base materials

CuZn5; CuZn10; CuZn15; CuSi2Mn; CuSi3Mn

Notes

Modified CuSi3 with silicon content between 2.8 - 2.95%, especially for Laserbrazing and MIG-brazing in the automotive industry. Wire surface is 100% eddy current controlled. Wire diameter is 100% laser controlled. There are no cold pressure welds of the wire within one drum or spool.

Application notes from page 67.

Properties approx. values

Electrical conductivity [S·m/mm²]	3–4
Density [kg/dm³]	8,5
Solidus-Temperature [°C]	910
Liquidus-Temperature [°C]	1025
Tensile strength R_m [MPa]	330–370
Elongation A_5 (L_0 = 5 d_0) [%]	40
Hardness [HB]	80–90

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (Argon, Helium or Argon-Helium-mixtures)
Polarity	MIG = +, TIG = –

Dimensions and packaging

MIG wire Ø [mm] 0,8 1,0 1,2 1,6

TIG rod Ø [mm] 1,6 2,0 2,4 3,2 4,0

Wire electrodes	Packaging unit
S 200 / 5 kg	–
S 300 / 15 kg	25 spools = 375 kg (Pallet)
B 300 / BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Drums	Packaging unit
ECO-drum / 200 kg	2 drums = 400 kg (Pallet)
JUMBO-drum / 200 kg	2 drums = 400 kg (Pallet)

Copper alloys › Data sheet

ML CuSi3.

Copper alloy welding rod/wire electrode

Typical composition of the filler metal in %

Al	Si	Mn	Sn	Zn	Pb	Fe	P	Others total
< 0,02	2,80–4,00	0,50–1,50	< 0,20	< 0,40	< 0,02	< 0,50	< 0,05	< 0,50

Classification

ISO 24373	S Cu 6560 (CuSi3Mn1)
DIN 1733	SG-CuSi3
Material no.	2.1461
BS 2901 part 3	C 9
AWS A 5.7	ER Cu Si - A

Base materials

CuZn5; CuZn10; CuZn15; CuSi2Mn; CuSi3Mn

Notes

Filler wire for joining Copper, Copper-Silicon and Copper-Zinc alloys. Suitable for joning of steel to Copper and for surfacing of steel. High temperature and corrosion resistance. Very commonly used for galvanized steel.

Application notes from page 67.

Properties approx. values

Electrical conductivity [S·m/mm²]	3–4
Density [kg/dm³]	8,5
Solidus-Temperature [°C]	910
Liquidus-Temperature [°C]	1025
Tensile strength R_m [MPa]	330–370
Elongation A_5 ($L_0 = 5\ d_0$) [%]	40
Hardness [HB]	80–90

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (Argon, Helium or Argon-Helium-mixtures)
Polarity	MIG = +, TIG = –

Dimensions and packaging

MIG wire Ø [mm]: 0,8 | 1,0 | 1,2 | 1,6

TIG rod Ø [mm]: 1,6 | 2,0 | 2,4 | 3,2 | 4,0

Wire electrodes	Packaging unit
S 200 / 5 kg	–
S 300 / 15 kg	25 spools = 375 kg (Pallet)
B 300 / BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Drums	Packaging unit
ECO-drum / 200 kg	2 drums = 400 kg (Pallet)
JUMBO-drum / 200 kg	2 drums = 400 kg (Pallet)

Current data sheet and stock level
migal.co/en/products/copper-welding-and-brazing-wire/ml-cusi3

ML CuSn.

Copper alloy welding rod/wire electrode

Typical composition of the filler metal in %

Al	Si	Mn	Ni incl. Co	Sn	Pb	Fe	P	Others total
< 0,01	0,10–0,40	0,10–0,40	< 0,10	0,50–1,00	< 0,01	< 0,03	< 0,015	< 0,20

Classification

ISO 24373	S Cu 1898A (CuSn1MnSi)
DIN 1733	SG-CuSn
Material no.	2.1006
BS 2901 part 3	C 7
AWS A 5.7	ER Cu

Base materials

OF-Cu; SE-Cu; SW-Cu; SF-Cu; CuZn0,5

Notes

Filler wire for joning of high-duty Copper materials. Excellent weldability. High quality welds without porosity for applications in construction and for pressure vessels.

Application notes from page 67.

Properties approx. values

Electrical conductivity [S·m/mm²]	15–20
Density [kg/dm³]	8,9
Solidus-Temperature [°C]	1020
Liquidus-Temperature [°C]	1050
Tensile strength R_m [MPa]	210–245
Hardness [HB]	60–80

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (Argon, Helium or Argon-Helium-mixtures)
Polarity	MIG = +, TIG = –

Dimensions and packaging

MIG wire Ø [mm] 0,8 1,0 1,2 1,6

TIG rod Ø [mm] 1,6 2,0 2,4 3,2 4,0

Wire electrodes	Packaging unit
S 200 / 5 kg	–
S 300 / 15 kg	25 spools = 375 kg (Pallet)
B 300 / BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Drums	Packaging unit
ECO-drum / 200 kg	2 drums = 400 kg (Pallet)
JUMBO-drum / 200 kg	2 drums = 400 kg (Pallet)

Copper alloys › Data sheet

ML CuSn6.

Copper alloy welding rod/wire electrode

Typical composition of the filler metal in %

Al	Zn	Sn	Pb	Fe	P	Others total
< 0,01	< 0,10	4,00–7,00	< 0,02	< 0,10	0,01–0,40	< 0,20

Classification

ISO 24373	S Cu 5180A (CuSn6P)
DIN 1733	SG-CuSn6
Material no.	2.1022
BS 2901 part 3	C 11
AWS A 5.7	ER CuSn - A

Base materials

CuSn4; CuSn6; CuSn8

Notes

Filler wire for joining and surfacing of bronzes. Tough and pore-free weld metal with a controlled content of Phosphor.

Application notes from page 67.

Properties approx. values

Electrical conductivity [S·m/mm²]	9
Density [kg/dm³]	8,7
Solidus-Temperature [°C]	910
Liquidus-Temperature [°C]	1040
Tensile strength R_m [MPa]	320–360
Elongation A_5 (L_0 = 5 d_0) [%]	25
Hardness [HB]	80–90

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	I1, I2, I3 (Argon, Helium or Argon-Helium-mixtures)
Polarity	MIG = +, TIG = –

Dimensions and packaging

MIG wire Ø [mm] 0,8 1,0 1,2 1,6

TIG rod Ø [mm] 1,6 2,0 2,4 3,2 4,0

Wire electrodes	Packaging unit
S 200 / 5 kg	–
S 300 / 15 kg	25 spools = 375 kg (Pallet)
B 300 / BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Drums	Packaging unit
ECO-drum / 200 kg	2 drums = 400 kg (Pallet)
JUMBO-drum / 200 kg	2 drums = 400 kg (Pallet)

Current data sheet and stock level
migal.co/en/products/copper-welding-and-brazing-wire/ml-cusn6

Brazing or welding.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHAT IS ARC BRAZING?

In arc brazing, an arc joins thin steel sheets with a copper-based wire, usually CuSi3Mn1 or CuAl8. The filler metal melts at around 1000 °C, the steel only at around 1500 °C. The base material therefore remains solid; the liquid filler metal merely wets it. The equipment is almost the same as for MIG/MAG welding.

The most common form is MIG brazing (GMA brazing): the copper-based wire is fed through the hose package like a welding wire and melts in the arc. There are also TIG and plasma brazing, in which the wire runs into the arc without current, and laser beam brazing as a related process. None of these processes needs a flux, because the arc cleans and activates the surface itself.

Physically, it is brazing: the joint is formed by wetting and diffusion at the interface, not by a common weld pool. Unlike furnace or flame brazing, however, there is hardly any capillary action. The filler metal does not fill a narrow gap but forms a seam as in welding, usually a fillet seam on a lap joint. Joint preparation is generally not necessary.

Which processes exist and how they differ is shown in Processes at a glance (page 68).

Why braze galvanised sheet instead of welding it?

Because zinc melts at 419 °C and evaporates at 907 °C, far below the melting temperature of the steel. In welding, the zinc evaporates over a wide area; the vapour disturbs the arc and causes pores and spatter. In brazing, the temperature stays lower and the zinc layer is damaged only on a narrow strip.

Next to a brazed seam on galvanised sheet, DVS 0938-1 describes two zones: directly at the seam a zinc-free zone in which the zinc has evaporated, and next to it a dark zone in which it has only melted and solidified again. With good settings, only the dark zone forms on the reverse side of the sheet. The zinc layer remains closed there and continues to protect.

This results in the well-known advantages:

- The corrosion protection layer is largely preserved, also on the reverse side and in cavities where re-protection is not possible.
- Hardly any spatter and pores from zinc vapour, less rework.
- Low heat input, therefore little distortion and hardly any burn-through on thin sheet.
- The brazed seam itself does not corrode like steel, because it consists of a copper alloy.
- Good gap bridging, especially with the pulsed arc.

According to DVS 0938-1, sheets with zinc coatings up to 15 µm can generally be brazed without problems. Thicker layers, for example on batch-galvanised parts, require separate trials. More on this under Base materials and coatings (page 74).

Brazing or MAG welding: the direct comparison

Feature	Arc brazing (MIG brazing)	MAG welding
Filler metal	copper-based wire, e.g. CuSi3Mn1 or CuAl8	steel wire, e.g. G3Si1
Melting temperature of the filler	around 900 to 1070 °C	around 1500 °C
Base material	is not melted, or only slightly	is melted
Zinc layer next to the seam	narrow zone, reverse side remains largely protected	evaporated over a wide area, re-protection needed
Spatter, pores from zinc vapour	little	considerably more
Distortion	low	greater
Strength of the seam	limited by the filler metal, tensile strength over 340 MPa (CuSi3Mn1)	matches the steel
Thickness	up to about 3 mm	no such limit
Seam colour	copper to gold coloured	like the steel

Guide values. Melting ranges and strength of the filler metals according to DVS 0938-1, Table 5 (manufacturer data for the pure braze metal). How much the zinc layer suffers depends mainly on the settings.

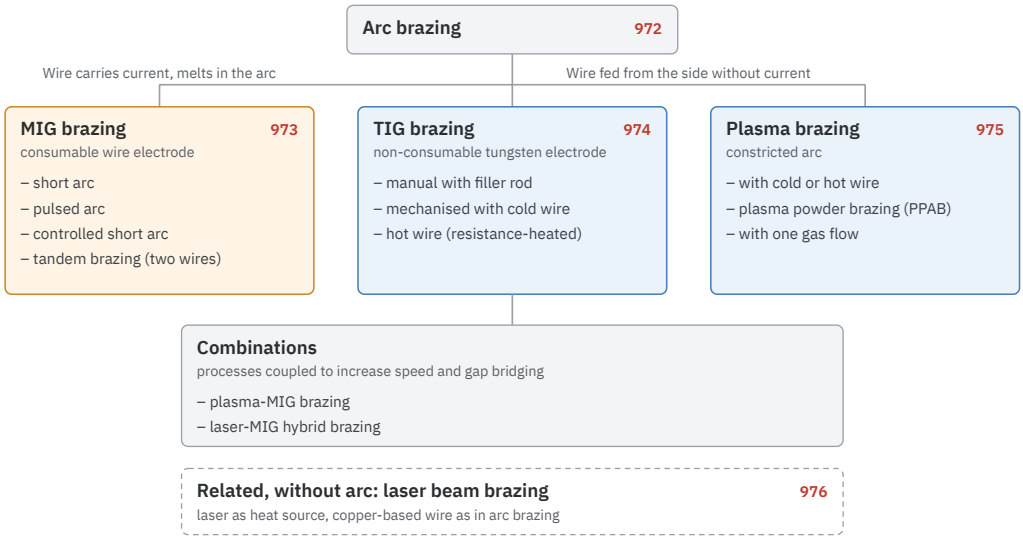
Also in the full article on migal.co: Where are the limits of arc brazing · Where is arc brazing used · Brazing or welding? A decision aid · Which brazing wire is suitable

Arc brazing processes.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHICH ARC BRAZING PROCESSES ARE THERE?

Three basic processes: MIG brazing (GMA brazing) with a consumable wire, and TIG brazing and plasma brazing with wire fed without current. In addition, there are variants such as pulsed and controlled short arc, tandem and hot-wire brazing, and combinations with plasma or laser. Laser beam brazing is closely related but works without an arc.



Reference numbers according to ISO 4063:2009 (group 97, braze welding). Variants according to DVS 0938-1:2012.

Arc brazing processes at a glance

Copper

The distinction that matters most in practice is the wire feed. In MIG brazing, the wire is also the electrode: current and wire quantity are linked, and feeding faster means more heat input. In TIG and plasma brazing, the arc burns on a tungsten electrode and the wire runs in from the side without current. Heat and filler metal quantity can be set separately. This gives particularly clean, spatter-free seams, but restricts mobility on the robot, because the wire must always point in the direction of travel.

Arc brazing is actually braze welding

In ISO 4063, the list of welding and brazing processes, arc brazing is listed under group 97, braze welding. This means brazing in which the filler metal is not drawn into a narrow gap by capillary action but, as in welding, forms a seam in a groove or fillet.

- **972** arc brazing (generic term)
- **973** gas metal arc weld brazing (MIG brazing)
- **974** gas tungsten arc weld brazing (TIG brazing)
- **975** plasma arc brazing
- **976** laser brazing (braze welding with the laser)

Classic brazing in a furnace, with a flame or by induction, on the other hand, is in groups 91 and 92. There the filler metal fills a narrow gap, usually with flux. Anyone specifying a brazed seam in the welding procedure specification or on the drawing therefore uses the numbers from group 97.

Combinations and laser

Where one process alone reaches its limit, two are coupled: plasma-MIG brazing and laser-MIG hybrid brazing combine the heat of one with the filler metal supply of the other. Laser beam brazing itself is not an arc process, but uses the same copper-based wires.

In car body construction, visible seams on the roof and tailgate are mostly laser brazed today, because the seam can be painted with almost no rework. More under Laser and hybrid brazing (page 71).

Also in the full article on migal.co: MIG, TIG and plasma brazing compared · MIG brazing: the most widely used process · TIG and plasma brazing: clean and precise · How do you specify a brazed seam on the drawing

Full article on migal.co
migal.co/en/service/arc-brazing/general-classification

MIG brazing.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHAT IS MIG BRAZING?

MIG brazing (GMA brazing) is MIG/MAG welding with a copper-based wire electrode, usually CuSi3Mn1 or CuAl8. The wire melts in the arc, the steel remains solid. Brazing is done with the short or pulsed arc at low power, with a short arc and a slightly pushing torch.

GUIDE VALUES FOR MIG BRAZING

Thickness	0,8 mm	1,0 mm	1,2 mm	1,5 mm	2,0 mm	3,0 mm
Voltage (rms)	15–17 V	16–17 V	17–18 V	17–18 V	18–20 V	19–23 V
Current (rms)	20–27 A	24–30 A	32–35 A	40–45 A	64–66 A	90–100 A
Pulse frequency	12–20 Hz	16–20 Hz	20 Hz	26–35 Hz	48–60 Hz	78–81 Hz
Pulse duration	1,5–2,0 ms	1,5–2,0 ms	1,6–2,2 ms	1,6–2,1 ms	1,7–2,1 ms	1,7–2,2 ms
Wire feed speed	1.2–1.5 m/min	1.5–2.0 m/min	1.8–2.2 m/min	2.1–3.0 m/min	3.2–4.7 m/min	5.0–6.0 m/min

Because the equipment is almost the same as for welding, MIG brazing is the most widely used arc brazing process. It works in all positions, by hand and on the robot, and usually without joint preparation. Depending on the shielding gas, it is called MIG brazing (argon) or MAG brazing (argon with a little CO_2 or O_2).

The aim is different from welding: the sheet should not melt, and the zinc layer should evaporate as little as possible. Almost every setting rule on this page follows from this: as little heat as necessary, as briefly as possible.

Which power source do you need for MIG brazing?

A power source that works stably between about 25 and 100 A and regulates quickly. For the short arc, a standard power source with a flat characteristic is sufficient; for the pulsed arc, an electronic power source with its own characteristic curve for the filler metal is used.

- **Adjustable far down:** thin galvanised sheet is brazed with very little power. The arc must burn steadily especially in the lower range.
- **Fast control:** if the wire stick-out changes while guiding the torch, the power source must readjust immediately; otherwise the short brazing arc becomes unstable.
- **Suitable characteristic curve:** in pulsed brazing, the correct pulse shape depends on the filler metal and shielding gas. Most pulse power sources have characteristic curves for CuSi3 and CuAl8; if one is missing, it is often available from the manufacturer.
- **Low background current:** in the pulsed arc, the background current determines a large part of the heat in the sheet. It must be set low.

Short arc, pulsed arc or controlled short arc?

The short arc is simple and low in heat; the pulsed arc produces less spatter, makes flatter seams and bridges gaps better. Controlled short arcs, which lower the current in the short circuit, combine both and are suitable for the thinnest sheet.

- **Short arc:** the droplet is transferred in the short circuit. This is the most common variant in repair work, because it works with any MIG/MAG machine and is easy to set.
- **Pulsed arc:** few short circuits and good control. It is the choice for fillet seams on lap joints with a gap and for visible seams. Here too: keep the arc as short as possible, because zinc vapour also makes the pulsed arc unsteady.
- **Controlled short arc:** current and voltage are deliberately lowered in the short circuit; in some systems the wire also reverses. Particularly low in spatter and heat.

According to a study by SLV München, the choice of arc has little influence on braze cracking: short arc, DC pulse and pulse with AC intermediate pulses produced a similar number of filler metal penetrations. The decisive factor was the heat input (Aicher and Cramer, DVS-Berichte 244, 2007).

Also in the full article on migal.co: Guide values for MIG brazing · How do you hold and guide the torch in MIG brazing · What does wire feeding need for copper wire · Which wire and which gas

Application notes › Arc brazing

TIG and plasma brazing.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHAT IS TIG BRAZING?

In TIG brazing, the arc burns between a tungsten electrode and the sheet. The filler metal is fed from the side without current, by hand as a rod or mechanised as cold wire. Because the arc and the filler metal quantity can be set separately, the heat in the sheet can be finely dosed.

GUIDE VALUES FOR PLASMA BRAZING

Thickness	0,6 mm	0,8 mm	1,0 mm	1,2 mm	1,5 mm	2,0 mm	3,0 mm
Pulse current	35–85 A	100–120 A					
Background current	17–42 A	50–60 A					
Voltage	23–32 V						
Pulse frequency	2,5–3,0 Hz						
Wire feed speed	2.5 m/min	2.7 m/min	4.0 m/min	5.7 m/min	6.5 m/min	8.5 m/min	11.0 m/min

This is the essential difference from MIG brazing (page 69): there the wire itself is the electrode, and more wire also means more current. In TIG brazing, the heat stays the same when you add more or less filler metal. Brazing is almost always done with a continuous arc, preferably in positions PA and PB.

By hand, the work is similar to flame brazing with a rod, only without flux. Mechanised, the wire runs into the arc from the side via a cold wire feeder. In the hot-wire process, the wire is additionally heated by resistance. This brings speed or less distortion.

When is TIG brazing worthwhile instead of MIG brazing?

When the seam is to be clean and spatter-free and the zinc layer next to the seam must be preserved as far as possible, for example for visible seams, small batch sizes or repairs. For fast series production and seams with awkward spatial access, MIG brazing is usually the better choice.

- **Zinc layer:** in a study by SLV München, the heat in TIG brazing could be controlled so that the zinc layer next to the seam was preserved. Only a narrow brass fringe formed at the seam edge; no open cracks occurred next to the seam.
- **Spatter:** according to DVS 0938-3, TIG and plasma brazing are regarded as spatter-free. Rework on visible surfaces is largely eliminated.
- **Limit: speed and accessibility:** the lateral wire feed makes the torch dependent on direction. For seams in all directions on the robot, this is a disadvantage.
- **Limit: dissolution:** in the same study, TIG brazed joints showed greater dissolution of the base material than MIG brazed joints. Brazing too slowly or letting the arc dwell too long melts the sheet.

With high-strength sheet, the clamping has a strong effect: on HCT600X, the number of small filler metal penetrations in TIG brazing rose from 2 to 13 with rigid clamping (Aicher and Cramer, DVS-Berichte 244, 2007). More on this under Seam defects and braze cracking (page 77).

What equipment do you need for TIG brazing?

Any standard TIG DC power source. A pulse power source is not necessary; 20 to 150 A is sufficient for most tasks. For mechanised brazing, a cold wire feeder is added.

- **Torch:** standard TIG torches. There are manual torches with an attached wire feed, controlled via the torch trigger.
- **Mechanised:** the wire feed is attached externally to the torch. Robot torches with external wire feed and an interface for torch changing are state of the art.
- **Ignition:** ignite contactlessly with high frequency, not by scratch start. This avoids tungsten inclusions in the seam.
- **Distance:** in automated brazing, a distance sensor keeps the arc length constant and prevents the electrode from dipping into the pool.

Also in the full article on migal.co: What is plasma brazing · What equipment do you need for plasma brazing · Guide values for plasma brazing · What variants are there · Which filler metal and which gas · Typical defects in TIG and plasma brazing

Copper

Full article on migal.co
migal.co/en/service/arc-brazing/tig-brazing

Laser and hybrid brazing.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHAT IS LASER BEAM BRAZING?

In laser beam brazing, a laser melts the filler wire, usually CuSi3; as in arc brazing, the steel stays solid. There is no arc, only a precisely placed focal spot. This produces very smooth seams at several metres per minute and little distortion.

Under ISO 4063, laser beam brazing, number 976, is a process in its own right alongside arc brazing (972). It belongs in this series because the filler metal, base material and seam shape are the same: galvanised sheet steel, copper-based filler metal, flange or fillet seam.

It is used mainly in high-volume car body production, for example on the roof and tailgate. There the seams are considered suitable for the outer skin: they are painted without significant rework and remain visible. If the wire is additionally heated electrically, this is called laser hot-wire brazing. It increases the speed further.

What does the laser offer compared with the arc?

Higher speed, less heat and a seam surface that can be painted without grinding. The price is high equipment costs, tight gap tolerances and an enclosed laser safety cell.

- **Surface:** the focal spot is small and uniform, the seam smooth. Spatter as in MIG brazing hardly occurs.
- **Heat:** the energy goes specifically into the filler metal. Distortion remains low, even on long outer skin seams.
- **Limits:** the laser needs precisely positioned components and precise wire feeding. For single parts, repairs or seams with a varying gap, MIG brazing (page 69) remains more economical.

Why is hot-dip galvanised sheet more difficult in laser brazing?

The surface of hot-dip galvanised sheet is less even than that of electrogalvanised sheet. With a single focal spot, the seams then become rougher and spatter. The remedy is optics with leading focal spots that clean the joint zone ahead of the filler metal.

In trifocal brazing, two small focal spots with high power density run ahead of the main spot. They vaporise dirt, oxides and part of the zinc layer and preheat the sheet. The main spot then melts the filler metal. The result is smooth seams with a clean edge, which are processed further without rework, and a larger bonding cross-section (Kessler, DVS-Berichte 327, 2016).

The leading spots can also be switched off on one side. In this way a steel-plastic composite sheet was brazed to galvanised sheet at 3 m/min without melting the plastic core.

What is laser-MIG hybrid brazing?

A laser and a MIG arc work in the same pool. The laser provides speed and a stable arc root position, the arc provides filler metal in large quantities and good gap bridging.

DVS 0938-1 lists laser-MIG brazing, together with plasma-MIG brazing, as a process combination that is being trialled. Both aim to combine the strengths of two heat sources. The plasma-MIG variant is described on the page TIG and plasma brazing (page 70).

Which filler metal for laser and hybrid brazing?

CuSi3Mn1 is the standard filler metal for galvanised sheet here too. Because laser and hybrid processes run fast, uniform wire is particularly important.

Diameter, cast and helix must be closely toleranced, the surface smooth and clean. At several metres per minute, even small variations shift the position of the wire relative to the focal spot. More on this under Wire feeding (page 75) and Filler metals and standard designations (page 72).

- ML CuSi3: standard filler metal for galvanised steel sheet
- all copper wires: Copper welding and brazing wire

Also in the full article on migal.co: MIG-TIG hybrid brazing: two arcs in one pool

Application notes › Arc brazing

Brazing fillers.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHICH FILLER METALS ARE USED FOR ARC BRAZING?

Almost always standardised copper-based solid wires to ISO 24373, usually 0.8 to 1.6 mm in diameter. The most common is CuSi3Mn1 for galvanised sheet, plus CuAl7 (formerly CuAl8) for aluminised sheet and visible seams, and tin bronzes for copper and brass parts.

THE USUAL FILLER METALS AT A GLANCE

Lot	ISO 24373	Melting range	Rp0,2	Rm	A5	Main application
CuSi3Mn1	Cu 6560	980–1035 °C	> 200 MPa	> 340 MPa	40 %	galvanised steel car body parts
CuSi2Mn1	Cu 6511	1030–1050 °C	> 100 MPa	> 290 MPa	45 %	galvanised steel car body parts
CuAl7	Cu 6100	1030–1040 °C	> 180 MPa	> 380 MPa	40 %	galvanised steel car body parts
CuAl5Ni2Mn	Cu 6061	1040–1070 °C	> 200 MPa	> 360 MPa	45 %	solenoid valves
CuSn1	Cu 1898	1020–1050 °C	> 80 MPa	> 220 MPa	25 %	copper vessel construction
CuSn6P	Cu 5180	910–1040 °C	> 150 MPa	> 260 MPa	20 %	brass and bronze parts

The filler metals melt between about 900 and 1070 °C, well below the steel. They are made for arc brazing: silicon, aluminium or tin ensure good wetting, and there are hardly any elements that vaporise in the arc.

- **Brass and nickel silver filler metals** are only suitable in exceptional cases according to DVS 0938-1. Their zinc vaporises in the arc.
- **Zinc-based filler metals** with melting ranges of around 380 to 450 °C were being trialled in 2012, for example for very thin sheet or thick zinc layers.
- **Non-standardised wires** and flux-cored wires are less common.

The usual filler metals at a glance

At 980 to 1035 °C, CuSi3Mn1 has the lowest melting range of the common filler metals and reaches a tensile strength of over 340 MPa. CuAl7 is stronger at over 380 MPa, but melts at a higher temperature.

Extract from DVS 0938-1:2012, Table 5. The strength values are manufacturers' data for the pure deposited filler metal and do not apply to the brazed joint. The table in the technical bulletin also gives the designations under ISO 17672 as well as filler metals for surfacing and zinc-based filler metals.

Copper-based wires are available in different heat treatment conditions. For robots with long hose packages, DVS 0938-1 recommends wires with higher strength, because they are easier to feed.

How do you read the standard designation under ISO 24373?

The designation ISO 24373 – S Cu 6560 (CuSi3Mn1) consists of three parts: S for solid wire or solid rod, Cu 6560 for the chemical composition and, optionally, the alloy symbol in brackets.

- **ISO 24373:** the standard for solid wires and solid rods of copper and copper alloys. It replaces DIN EN 14640 and, before that, DIN 1733.
- **S:** the product form. Wire and rod both carry the S; one product form can be used for several processes.
- **Cu 6560:** the numerical designation of the composition. It alone is binding.
- **(CuSi3Mn1):** the alloy symbol, for readability.

As a brazing filler metal under ISO 17672, the same alloy is designated Cu 541. On a drawing, a MIG-brazed seam is specified, for example, as ISO 4063-973 / ISO 24373 – S Cu 6560 (CuSi3Mn1), see Arc brazing processes at a glance (page 68).

Old and new designations of our brazing wires

The old DIN names still appear on drawings and orders. The table maps them to the current ISO designation and the American AWS classification.

ML CuSi28L has the same standard designation as ML CuSi3, S Cu 6560 (CuSi3Mn1). All wires: Copper welding and brazing wire.

Also in the full article on migal.co: CuAl8 or CuAl7: are they the same · CuSi3 or CuAl8: which filler metal for what · How hot may a brazed joint get in service · What matters with brazing wire

Copper

Full article on migal.co
migal.co/en/service/arc-brazing/filler-metals

Shielding gas.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHICH SHIELDING GAS IS USED FOR ARC BRAZING?

Pure argon always works. For CuSi3 and tin bronzes in MIG brazing, argon with a little CO_2 or O_2 is often better; for aluminium-containing filler metals such as CuAl8, stay with argon or argon-helium without an active component.

According to DVS 0938-1, brazing is usually done with argon (group I1 to ISO 14175) or with argon mixtures to which small amounts of CO_2 or O_2 have been added. The gas protects filler metal and sheet from air and replaces the flux that would be needed in flame brazing.

Filler metal / process	Shielding gas	ISO 14175	Note
CuSi3Mn1, MSG	argon or argon with a little CO_2 or O_2	I1, M12, M13	the active component steadies the arc and reduces pores, but adds more heat
CuSn filler metals, MIG	argon or argon with a little CO_2 or O_2	I1, M12, M13	as for CuSi3
CuAl7 (CuAl8), MSG	argon or argon-helium, without active component	I1, I3	without active component according to DVS 0938-1
TIG brazing	Argon	I1	the tungsten electrode does not tolerate an active component
Plasma brazing	argon as shielding and plasma gas	I1	plasma gas around 0.9 l/min according to DVS 0938-1

Assignment according to DVS 0938-1:2012, section 5.3.2. The ISO 14175 groups are examples: I1 argon, I3 argon with helium, M12 argon with 0.5 to 5 % CO_2, M13 argon with 0.5 to 3 % O_2.

What do carbon dioxide and oxygen do in the brazing gas?

Small amounts of CO_2 or O_2 stabilise the arc, reduce the tendency to porosity and lower the surface tension of the filler metal pool. In return, the heat in the base material increases.

- **Steadier arc:** the arc root jumps less, especially on a galvanised surface with zinc vapour.
- **Better wetting:** according to DVS 0938-3, active components can reduce the surface tension of the brazing pool. This helps when the filler metal does not flow well or the seam is too high.
- **More heat:** that is the price. With thin sheet or a tendency to braze cracking, you therefore stay with the smallest active component that keeps the arc steady.

As a guide: in the trials at SLV München on braze cracking, CuSi3 was brazed under argon with 2.5 % CO_2, CuAl8 and all TIG brazing under pure argon (Aicher and Cramer, DVS-Berichte 244, 2007).

Which gas for CuAl8?

Argon or argon-helium, without carbon dioxide and oxygen. This is what DVS 0938-1 recommends for filler metals containing aluminium, and this is how CuAl8 was brazed in the trials at SLV München.

Helium makes the arc hotter and wider, which improves the flow of the aluminium bronze filler metal. Pure argon also works. CuAl8 is not suitable for TIG and plasma brazing anyway, see TIG and plasma brazing (page 70).

Nitrogen and hydrogen: what needs to be considered?

Neither normally belongs in the brazing gas. Nitrogen does stabilise the arc and makes the seam wider, but it can cause very considerable porosity. Hydrogen increases the speed, but also leads to pores.

When brazing dissimilar joints with pure copper, especially with phosphorus-deoxidised copper Cu-DHP, no hydrogen-containing gases may be used according to DVS 0938-1.

How much gas do you need?

In the guide values of DVS 0938-1, it is 12 l/min argon with 1.0 mm wire, for MIG as well as plasma brazing. In plasma brazing, around 0.9 l/min argon is added as plasma gas.

More gas is not better. Too high a gas flow rate causes turbulence and draws air into the gas shield, which produces pores just as too little gas does. Adjust the gas flow rate to the nozzle diameter and torch distance and avoid draughts at the workplace. Settings for MIG brazing: MIG brazing (page 69).

Also in the full article on migal.co: Pores despite shielding gas: what to check

Base materials.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHICH MATERIALS CAN BE ARC BRAZED?

> Above all thin sheet of unalloyed and low-alloy steel up to 3 mm, uncoated or with a metallic coating, usually galvanised. The process was developed for these.

Arc brazing started with unalloyed deep-drawing steels under 3 mm. DVS 0938-2 lists combinations whose suitability has been demonstrated in the tensile shear test with CuSi3, including DC05, the galvanised deep-drawing grades DX53D to DX55D and the higher-strength grades H180B, H220P, H260LA and H340LA.

Thicker components are possible, but not standard. In a research project in Rostock, hot-dip galvanised seawater pipes with a wall thickness of 4 to 8 mm were MIG brazed, with around 30 % less processing time than welding followed by re-galvanising (Wanner and others, DVS-Berichte 275, 2011).

How thick may the zinc layer be?

According to DVS 0938-1, zinc layers up to about 15 µm are considered unproblematic. With thicker layers, for example hot-dip or batch galvanised parts with a thick coating, additional trials are needed.

The more zinc, the more vapour, pores and spatter. For thick layers, the technical bulletin also mentions zinc-based filler metals as an option. In practice, low heat helps most: short arc, pushing torch, suitable characteristic, see MIG brazing (page 69).

Whether electrogalvanised or hot-dip galvanised: in MIG brazing, some zinc always vaporises next to the seam and on the reverse side of the sheet. In laser brazing, hot-dip galvanised sheet produces rougher seams with a single focal spot, see Laser and hybrid brazing (page 71).

Is the corrosion protection next to the seam retained?

Largely, but not completely. A narrow zinc-free margin remains next to every brazed seam. Rust can form there, and the wider the margin, the faster.

In investigations in Chemnitz on electrogalvanised and hot-dip galvanised sheet, red rust formed in the salt spray test on all brazed specimens in the dezincified area next to the seam, from a margin width of just 0.5 mm. The corrosion was directly proportional to the width of the dezincified zone. Spatter on the surface had no margin and was not a starting point for corrosion. The white rust on the melted zinc layer on the reverse side did not impair the corrosion protection (Kusch and Podlesak, DVS-Berichte 275, 2011).

- **Keep the margin narrow:** short arc, low heat. Larger seam volumes cover more of the margin.
- **Components at risk of corrosion:** paint or coat them, matching the coating to the attack. Systems customary for galvanised sheet, such as cathodic electrocoating, also cover the brazed seam.
- **Gaps:** avoid or seal them so that no moisture collects.

The advantage over welding remains: copper-based filler metals reduce zinc vaporisation and maintain the corrosion protection in the seam area too, as Kusch and Podlesak state in their introduction.

Aluminised and organically coated sheet

For aluminised sheet, DVS 0938-1 recommends aluminium-containing copper filler metals such as CuAl7, usually sold as CuAl8. Organically coated galvanised sheet can be brazed, but the parameters must be adjusted.

On the filler metal: ML CuAl8; on the gas without an active component: Shielding gas (page 73).

Can higher-strength steels be arc brazed?

Yes, but not without testing. The filler metal is usually less strong than the steel, and higher-strength sheet is more prone to filler metal penetration. DVS 0938-2 advises demonstrating suitability for the individual case.

- **Strength:** with specimens of HCT600X, the joint did not reach the tensile strength of the filler metal in any case; the fracture was at the transition from filler metal to sheet. A larger bonding area, for example through a small gap or more seam volume, increased the strength (Kusch and Podlesak, 2011).
- **Braze cracks:** in the trials at SLV München, the number of defects in high-strength dual-phase and complex-phase steels was up to 35 % higher than in higher-strength and conventional sheet. Rigid clamping roughly doubled the filler metal penetration.
- **Formed areas:** DX54D pre-strained by 20 % showed cracks, at 10 % pre-strain it did not (Aicher and Cramer, DVS-Berichte 244, 2007).

Causes and remedies: Seam defects and braze cracking (page 77).

Also in the full article on migal.co: Can stainless steel be arc brazed · Dissimilar joints: copper with steel · How must the surface be prepared

Wire feeding.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHY IS COPPER WIRE HARDER TO FEED THAN STEEL WIRE?

> Because copper-based wires such as CuSi3 or CuAl8 are softer. DVS 0938-1 therefore places higher demands on the feeder, hose package and torch than in steel welding.

In brazing, there is also the fact that the process has little leeway. Brazing is done with a short arc and low power. If the wire speed fluctuates, the arc length immediately fluctuates and with it the heat in the sheet. The result is irregular seams, pores or melted sheet. For periodic seam faults, DVS 0938-3 therefore names as the first step: check the wire feeding.

What does the feeder need?

A drive with constant speed and rolls that do not deform the soft wire. According to DVS 0938-1, the usual four-roll drives with U-groove for steel are not sufficient as they are.

- **Feed rolls:** rolls with a rounded groove, as for aluminium. Set the pressure only as high as necessary. Too little pressure makes the speed fluctuate, too much squashes the wire.
- **Constant speed:** the feed motor must hold the set speed even under changing load.
- **Power source:** if the stick-out changes while the torch is being guided, the power source must readjust quickly. More on this under MIG brazing (page 69).

Hose package and torch: when do you need push-pull?

From about 4 m of hose package in manual brazing and from 1.5 m on the robot, DVS 0938-1 recommends a second drive, for example at the torch. Always keep hose packages as short as possible.

- **Plastic liner:** mandatory for copper wire, no steel spiral. Guide it without gaps as close as possible to the rolls and contact tip; replace worn or dirty liners.
- **Robot:** water-cooled torches are recommended. In plasma brazing, a drive sits close to the torch; light two-roll drives improve accessibility there.
- **Routing:** route the hose package without tight loops. Every bend increases the friction.

Older documents still give 3 m for the push-pull torch. The edition of DVS 0938-1 currently in force, from 2012, gives 4 m for manual brazing.

Why are cast and helix so important?

Because they determine how the wire comes out of the contact tip and where it meets the sheet. DVS 0938-1 requires diameter, cast and helix to be closely toleranced.

- **Cast:** the curvature of the freely hanging wire, measured as the diameter or radius of one full turn. If it is too small, the wire presses hard against the wall of the liner and contact tip.
- **Helix:** the twist of the wire along its axis, measured as the distance of the wire end from a flat surface. Too much helix makes the wire tip wander.

In addition, the technical bulletin lists defects that must be avoided at all costs: longitudinal scores on the wire, diameter outside tolerance, waviness and welds in the wire. They lead to process faults.

With fast processes such as laser or hybrid brazing, this counts double: at several metres per minute, small deviations shift the position of the wire relative to the focal spot, see Laser and hybrid brazing (page 71).

Soft or stiff wire?

For robots with long hose packages, DVS 0938-1 recommends wires with higher strength. They are easier to push and buckle less.

Copper-based wires are supplied in different heat treatment conditions. For special applications, it should be checked whether wires of medium or low strength are suitable. On the filler metals themselves: Filler metals and standard designations (page 72).

How do you feed brazing wire from a drum?

With a short, well-routed feed path and, over longer distances, with a low-friction conduit or an additional drive. For drums, DVS 0938-2 explicitly points to the routing of the wire feed.

The principle is the same as with soft aluminium wire: if the wire is pulled through a long hose, the friction rises sharply with every bend. The calculation is on the page Wire feeding for aluminium welding (page 48).

- **Drawing off:** Drum hoods and decoiling aids guide the wire as it is drawn out of the drum.
- **Rollers instead of sliding friction:** in the Rolliner 3G, Rolliner NG and Rolliner XL2, the wire runs over pairs of rollers.
- **Second drive:** the pneumatic feed assist DLDA1 or RoboFeed push the wire on over long distances.

All accessories are listed under Wire transport. We are happy to advise on designing the feed path.

Joint types.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHICH JOINT TYPES CAN BE ARC BRAZED?

Essentially fillet seams, flange seams and square butt seams on sheet up to 3 mm. In production, the fillet seam on a lap joint predominates; in repair, the square butt seam on a butt joint.

Unlike furnace or flame brazing, arc brazing draws hardly any filler metal into a narrow gap. The capillary action is low, and the filler metal lies on the joint as a bead, as with a weld. Joint preparation is therefore usually not needed.

Joint types and favourable gap widths

For almost all joint types: gap below 1.5 times the thinner sheet thickness t_{min}, 2 mm at most. For corner joints and edge seams, the limit is 1.5 mm.

Joint and seam	favourable gap	maximum
Fillet seam on a lap joint	below 1.5 × t_{min}	2 mm
Fillet seam on a joggled lap joint	below 1.5 × t_{min}	2 mm
Fillet seam on a lap joint, three sheets	each gap below 1.5 × t_{min}	both gaps together 3 mm, sheets usually around 1 mm
Flange seam	below 1.5 × t_{min}	2 mm
Square butt seam on a butt joint	below 1.5 × t_{min}	2 mm
Fillet seam on a T-joint	below 1.5 × t_{min}	2 mm
Fillet seam on a corner joint	below 1.5 × t_{min}	1,5 mm
Edge seam	below 1.5 × t_{min}	1,5 mm

Gap widths to DVS 0938-1:2012, Table 6, for usual sheet thicknesses up to 3 mm. t_{min} is the thickness of the thinner sheet.

Fillet seam on a lap joint: the standard seam

The sheets lie on top of each other, and the filler metal fills the fillet between the edge of the upper sheet and the lower sheet. The seam is easy to prepare, tolerates variations and is the seam most often brazed in car body construction.

- **Torch:** Aim the arc at the edge of the upper sheet and the lower sheet. If the upper sheet melts, the heat is too high or the torch angle is too large. Settings: MIG brazing (page 69).
- **Joggled lap joint:** One sheet is joggled by about the sheet thickness. This keeps the surfaces roughly flush, for example on visible outer surfaces.
- **Three sheets:** possible if the sheets are around 1 mm thick and both gaps together do not exceed 3 mm.

Flange seam: joining thin sheets at the edge

In a flange seam, the sheet edges are bent up, and the filler metal joins the flanges at their top edge. It is typical on thin car body sheet, for example in laser brazing of roof seams.

Because the flange is formed, it is under stress. That is exactly where SLV München found the damage, in the bending tension zone of the flange joint (Aicher and Cramer, DVS-Berichte 244, 2007). DVS 0938-1 generally advises against brazing on deformed contours under tensile stress because of the risk of filler metal penetration. For flange seams this means: avoid tight bending radii and heavily pre-stretched sheet. More in Seam defects and braze cracking (page 77).

How important is the gap?

A small gap helps strength; a large one harms the seam. The filler metal flows into the gap and enlarges the bonded area, but as the gap widens, the number of pores rises.

In investigations in Chemnitz, a gap tended to increase joint strength because the bonding area between filler metal and lower sheet grew. Gaps above 0.5 mm, on the other hand, made the number of pores rise markedly (Kusch and Podlesak, DVS-Berichte 275, 2011).

Larger gaps can be filled with a weaving torch or a backing support. It is better to avoid them by design.

Also in the full article on migal.co: Design rules for brazed components

Copper

Full article on migal.co
migal.co/en/service/arc-brazing/joint-design

Weld defects.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHICH DEFECTS OCCUR IN ARC BRAZING?

Above all pores, spatter, zinc burn-off beside the seam and shape defects such as a seam that is too high. Also typical of brazing is braze cracking (liquid metal embrittlement): filler metal penetrates the steel along the grain boundaries.

DVS 0938-3 describes the imperfections of arc-brazed seams, based on the catalogues for brazing (ISO 18279) and gas-shielded welding (ISO 5817), and assigns measures to each defect. Defects caused by flux or slag do not occur, because brazing is done without flux and usually in a single pass.

Defect	common cause	first remedy
Porosity	zinc vapour, contamination, disturbed gas shielding	less heat, escape space, check gas supply
Spatter	zinc vapour, unsuitable arc type, thick zinc layer	pulsed arc instead of short arc, start programme, clean gas nozzle
Zinc burn-off, white flakes	too much heat input per unit length	reduce energy, conduct heat away via clamping jaws
Lack of bonding and incomplete filling	torch position, gap, arc blow	correct torch, check gap, move earth connection
Excess seam height	too much filler metal, voltage too low	increase voltage, adjust amount of filler metal
Erosion of the base material, burn-through	too much heat	reduce energy, correct torch position, inert gas
End crater cracks and hot cracks	shrinkage, clamping, long seams	crater-fill programme, free shrinkage, shorter seams
Filler metal penetration, braze crack	stress in the sheet plus heat	reduce energy, move seam out of formed areas
Tungsten inclusion	scratch start, electrode in the pool	HF ignition, keep distance

Summarised from DVS 0938-3:2012, Table 1. A defect can have several causes, and several measures often help.

Pores: causes and remedies

The most common cause is zinc vapour. It forms under the arc and must escape before the filler metal solidifies. The more heat and the tighter the space, the more pores.

- **Heat:** short arc, slightly pushing torch, no more energy than necessary. Give the pool time to degas. Settings: MIG brazing (page 69).
- **Design:** Provide escape space for the zinc vapour. A gap helps, but above 0.5 mm the number of pores rises markedly again; see Joint types and seam geometry (page 76).
- **Cleanliness:** Remove oil, wax and adhesive from the sheet. The wire can also cause pores: follow the manufacturer's storage instructions and avoid condensation.
- **Gas:** Check hose, connections, cooling water, draughts and gas flow; see Shielding gas (page 73).

How bad are pores? In tests on the fillet seam on a lap joint, porosity played a minor role for strength as long as the seam was continuous. Only pores in the bonding area between filler metal and sheet were critical (Kusch and Podlesak, DVS-Berichte 275, 2011). Open surface pores are nevertheless not permitted in visible areas and areas at risk of corrosion.

Spatter and zinc burn-off

Both come from too much energy or an unsteady arc on the zinc layer. White zinc oxide flakes beside the seam are a clear sign that the power is too high.

- **Arc:** pulsed arc instead of short arc where possible. TIG and plasma brazing are considered spatter-free. A start programme helps against spatter on ignition.
- **Zinc layer:** The type of galvanising affects spatter and how well it adheres. DVS 0938-3 states, for hot-dip galvanised sheet, preferably no more than 15 µm.
- **Filler metal:** no filler metals with readily evaporating constituents such as zinc.
- **Zinc burn-off:** Reduce the heat input per unit length and conduct heat away from the vulnerable area via clamping jaws or backing plates.

Brazing spatter adheres flat to the galvanised sheet, unlike the spherical spatter from welding. It hardly comes off with hammer and chisel; on visible surfaces it has to be ground. It does not, however, cause rust spots. How the zinc-free margin beside the seam corrodes is explained in Base materials and coatings (page 74).

Also in the full article on migal.co: Lack of bonding, incomplete filling and seams that are too high · End crater cracks and hot cracks · What is braze cracking · How are brazed seams assessed

Testing, rework, occupational safety.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

HOW ARE ARC-BRAZED SEAMS TESTED?

Like welds: non-destructively by visual inspection, dye penetrant, ultrasonic or radiographic testing, and destructively in tensile, peel or metallographic section tests. Which test makes sense depends on how the component is loaded.

Test	shows	Note
Visual inspection	external condition	based on ISO 5817, with an illuminated magnifier
Dye penetrant testing	open cracks	qualitative result
Ultrasonic testing	flaws parallel to the surface	documented as a C-scan
Radiography	flaws perpendicular to the surface	documented as a radiograph
Shear tensile test	strength of the joint	most common specimen, also as an H-specimen with several seams
Peel test	strength under peel loading	often corresponds to the real loading on flanges
Fatigue strength	endurance limit	e.g. on H-specimens
Drop-weight test	behaviour under impact	hat profile with a closed cross-section
Metallographic section and hardness	internal condition, pores, cracks, filler metal penetration	macro or micro section

Selection based on DVS 0938-1:2012, Table 7, and DVS 0938-2:2005, Section 3.2.

Most specimens are tested in shear tension. DVS 0938-2 points out, however, that on car body flanges the real loading is often peel. Before testing, you should therefore clarify how the component is actually loaded.

When is a brazed seam acceptable?

When the specimen breaks not in the seam but in the sheet. The brazed seam should achieve at least the properties of the weaker joining partner.

If the specimen breaks in the brazed seam, DVS 0938-2 recommends checking whether a different filler metal, a different process or a different design achieves the goal. There is no dedicated standardised assessment system for arc-brazed seams. You decide case by case or follow ISO 18279 and ISO 5817.

Guidance from DVS 0938-2: cracks are not permitted in the seam. Internal pores and inclusions up to about 20 % of the projected area in the section can be tolerated; open pores in visible areas and areas at risk of corrosion cannot. For dynamically loaded components, the wetting angle should be below 90°. Defect types and causes: Seam defects and braze cracking (page 77).

How is a brazed seam reworked?

Much as in welding: grind out and re-braze, always with filler metal of the same type. Each company sets out the type and extent of rework in its own instructions.

Finding	Rework
open pores, porous or scaly seam	re-braze or repair, grinding out beforehand if necessary
surface cracks in the filler metal	grind out completely, re-braze with filler metal of the same type
lack of bonding and wetting defects	grind out, re-braze with filler metal of the same type
sunken seam, fillet too small, missing seam	re-braze with filler metal of the same type
spatter, excess seam height, melted spots	grind off or remove with a suitable tool
undercuts, start and end craters	according to the company's own rework instructions

Examples based on DVS 0938-1:2012, Table 8. Company-specific rules take precedence. Depending on the company, rework is not permitted for burn-through and cracks in the base material.

- **MIG brazed with CuSi3:** re-brazing with filler metal of the same type is possible without problems.
- **Brazed with CuAl8:** only to a limited extent, because an aluminium oxide layer forms on the seam and can cause lack of bonding. DVS 0938-2 names TIG brazing with alternating current for this.
- **Never weld over:** A brazed seam must not be welded over, even after grinding it off. The base material risks embrittlement and cracking.

Also in the full article on migal.co: What should you watch for in grinding and painting · Which health and safety rules apply

Copper

Full article on migal.co
migal.co/en/service/arc-brazing/occupational-health

Wire electrodes and welding rods

Stainless steels.

8 filler metals for stainless steels: standard austenitic grades, filler metals for dissimilar joints and heat-resistant steels, and duplex. The filler metals with increased silicon content (LSi, NbSi) are matched to MAG welding.

ML 19.9 LSi	308LSi	1.4316	80
ML 23.12 LSi	309LSi	1.4332	81
ML 29.9	312	1.4337	82
ML 18.8 Mn	307	1.4370	83
ML 19.12.3 LSi	316LSi	1.4430	84
ML 22.9.3 NL	2209	1.4462	85
ML 19.12.3 NbSi	318Si	1.4576	86
ML 25.20	310	1.4842	87

Application notes. Material groups, delta ferrite, shielding gases, root protection and temper colours: notes on welding stainless steels from page 88.

Stainless materials › Data sheet

ML 19.9 LSi 1.4316 · 308LSi.

Stainless steel wire electrodes/welding rods

Typical composition of the filler metal in %

C	Si	Mn	P	S	Cr	Ni	Mo	Co	Cu	N
≤ 0,025	0,90	1,80	≤ 0,025	≤ 0,015	20	10,5	≤ 0,5	≤ 0,2	≤ 0,2	0,06

Classification

EN ISO 14343-A/G	19 9 L Si
DIN 8556	1.4316
AWS ER	308LSi

Base materials

Zum Schweißen stabilisierter und nichtstabilisierter, nichtrostender Cr-Ni-Stähle, z.B. 1.4301, 1.4306, 1.4541, 1.4550, für Betriebstemperaturen bis 350° C. Tieftemperaturanwendung bis -269°C, abhängig vom Schweißprozeß. Auch für Stähle mit max. 19% Chrom.

Resistance against corrosion

Good resistance to general and, owing to the low C content, intergranular corrosion.

Application notes from page 88.

Properties approx. values

Yield strength $R_{p0,2}$ [MPa]	390 (20 °C); 290 (400 °C)
Tensile strength R_m [MPa]	600 (20 °C); 440 (400 °C)
Elongation A [%]	42 (20 °C); 24 (400 °C)
Reduction of area [%]	60
Notched impact strengthV [J]	120 (20 °C); 50 (–196 °C)
Hardness [Vickers]	160
Ferrite number from standard analysis DeLong	11
Heat conductivity at temperature °Celsius	20; 100; 300; 500
Heat conductivity [W/m °C]	15; 16; 19; 21
Thermal expansion per °C, from 20°C - 400°C	$18 \cdot 10^{-6}$
Density [g/cm³]	7,9

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	MIG: Ar+1-3% O_2, Ar+1-3% CO_2, Ar+He+O_2, Ar+He+CO_2, Ar+He+CO_2+H_2 TIG: Ar, He, Ar+He, Ar+2-5% H_2
Polarity	MIG = +, TIG = –
Approvals	TÜV, DB

Dimensions and packaging

MIG wire Ø [mm] 0,8 | 1,0 | 1,2 | 1,6

TIG rod Ø [mm] 1,0 | 1,2 | 1,6 | 2,0 | 2,4 | 3,2 | 4,0

Wire electrodes	Packaging unit
BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Drums	Packaging unit
ECO-drum / 250 kg	2 drums = 500 kg (Pallet)

Current data sheet and stock level
migal.co/en/products/stainless-steel-welding-wire/4316-308lsi-ml-199-lsi

ML 23.12 LSi 1.4332 · 309LSi.

Stainless steel wire electrodes/welding rods

Typical composition of the filler metal in %

C	Si	Mn	P	S	Cr	Ni	Mo	N
≤ 0,025	0,90	1,80	≤ 0,025	≤ 0,015	23,5	13,5	≤ 0,4	0,10

Classification

EN ISO 14343-A/G	23 12 L Si
DIN 8556	1.4332
AWS ER	309LSi

Base materials

Verbindungsschweißen von Kombinationen verschiedener Stahltypen z.B. austenitischen nichtrostenden Stählen mit unlegierten/niedriglegierten Stählen. Zum Schweißen nichtrostender Cr-Ni-Stähle vom Typ 22 12 und Cr-Stähle, z.B. in der KfZ-Industrie.

Resistance against corrosion

The corrosion resistance is similar to that of the respective parent metal.

Application notes from page 88.

Properties approx. values

Yield strength $R_{p0,2}$ [MPa]	400
Tensile strength R_m [MPa]	600
Elongation A [%]	35
Reduction of area [%]	55
Notched impact strengthV [J]	140
Hardness [Vickers]	200
Ferrite number from standard analysis DeLong	10
Heat conductivity at temperature °Celsius	20; 100; 300; 500
Heat conductivity [W/m °C]	14; 15; 17; 19
Thermal expansion per °C, from 20°C - 400°C	$18 \cdot 10^{-6}$
Density [g/cm³]	7,9

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	MIG: Ar+1-3% O_2, Ar+1-3% CO_2, Ar+He+O_2, Ar+He+CO_2, Ar+He+CO_2+H_2 TIG: Ar, He, Ar+He, Ar+2-5% H_2
Polarity	MIG = +, TIG = –
Approvals	TÜV

Dimensions and packaging

MIG wire Ø [mm] 0,8 1,0 1,2

TIG rod Ø [mm] 1,0 1,2 1,6 2,0 2,4 3,2 4,0

Wire electrodes	Packaging unit
BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Drums	Packaging unit
ECO-drum / 250 kg	2 drums = 500 kg (Pallet)

Stainless

Stainless materials › Data sheet

ML 29.9 1.4337 · 312.

Stainless steel wire electrodes/welding rods

Typical composition of the filler metal in %

C	Si	Mn	P	S	Cr	Ni	Mo	Cu
≤ 0,10	0,40	1,80	≤ 0,025	≤ 0,015	30,5	9,20	≤ 0,3	≤ 0,3

Classification

EN ISO 14343-A/G	29 9
DIN 8556	1.4337
AWS ER	312

Base materials

Suitable for joining or cladding identical or similar steels or steel castings. Tough joints of un- and low alloyed structural steels with higher strength, as well as Manganese steels and CrNiMn steels, between different materials, i.e. between stainless or heatresistant and un/lowalloyed steels and steel castings.

Resistance against corrosion

Good resitsnace against wet corrosion up to 300° celsius. Additionally high resistance against hotcracking and good toughness at high yield strength.

Application notes from page 88.

Properties approx. values

Yield strength $R_{p0,2}$ [MPa]	500
Tensile strength R_m [MPa]	750
Elongation A [%]	20
Notched impact strengthV [J]	25

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	MIG: Ar+1-3% O_2, Ar+1-3% CO_2, Ar+He+O_2, Ar+He+CO_2, Ar+He+CO_2+H_2 TIG: Ar, He, Ar+He, Ar+2-5% H_2
Polarity	MIG = +, TIG = –

Dimensions and packaging

MIG wire Ø [mm]: 0,8 | 1,0 | 1,2 | 1,6

TIG rod Ø [mm]: 1,0 | 1,2 | 1,6 | 2,0 | 2,4 | 3,2 | 4,0

Wire electrodes	Packaging unit
BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Drums	Packaging unit
ECO-drum / 250 kg	2 drums = 500 kg (Pallet)

Current data sheet and stock level
migal.co/en/products/stainless-steel-welding-wire/4337-312-ml-299

ML 18.8 Mn 1.4370 · 307.

Stainless steel wire electrodes/welding rods

Typical composition of the filler metal in %

C	Si	Mn	P	S	Cr	Ni	Co	Cu	N
0,08	0,90	7,00	≤ 0,025	≤ 0,015	18,00	8,00	≤ 0,50	≤ 0,10	0,06

Classification

EN ISO 14343-A/G	18 8 Mn
DIN 8556	1.4370
AWS ER	307

Base materials

Zum Schweißen kaltverfestigender Stähle, Panzerplatten, austenitischer Mn-Stähle. Auch für nichtrostende Stähle mit ca. 18% Chrom, z.B. in der Kfz-Industrie. Verbindungsschweißungen von Kohlenstoff- und niedriglegierten Stählen mit Cr-Ni- und Cr-Ni-Mo-Stählen und für Auftragsschweißungen. (Bei Anlagen in überwachungspflichtigen Anlagen bis max. 300°C).

Resistance against corrosion

The corrosion resistance is similar to that of the respective parent metal.

Application notes from page 88.

Properties approx. values

Yield strength $R_{p0,2}$ [MPa]	460
Tensile strength R_m [MPa]	650
Elongation A [%]	41
Reduction of area [%]	61
Notched impact strengthV [J]	140
Hardness [Vickers]	200
Heat conductivity at temperature °Celsius	20; 100; 300; 500
Heat conductivity [W/m °C]	15; 16; 18; 20
Thermal expansion per °C, from 20°C - 400°C	$18 \cdot 10^{-6}$
Density [g/cm³]	7,8

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	MIG: Ar+1-3% O_2, Ar+1-3% CO_2, Ar+He+O_2, Ar+He+CO_2, Ar+He+CO_2+H_2 TIG: Ar, He, Ar+He, Ar+2-5% H_2
Polarity	MIG = +, TIG = –
Approvals	TÜV, DB

Dimensions and packaging

MIG wire Ø [mm]: 0,8 | 1,0 | 1,2 | 1,6

TIG rod Ø [mm]: 1,0 | 1,2 | 1,6 | 2,0 | 2,4 | 3,2 | 4,0

Wire electrodes	Packaging unit
BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Drums	Packaging unit
ECO-drum / 250 kg	2 drums = 500 kg (Pallet)

Stainless materials › Data sheet

ML 19.12.3 LSi 1.4430 · 316LSi.

Stainless steel wire electrodes/welding rods

Typical composition of the filler metal in %

C	Si	Mn	P	S	Cr	Ni	Mo	Co	Cu	N
≤ 0,025	0,90	1,80	≤ 0,025	≤ 0,015	18,50	12,00	≤ 2,60	≤ 0,20	≤ 0,20	0,06

Classification

EN ISO 14343-A/G	19 12 3 L Si
DIN 8556	1.4430
AWS ER	316LSi

Base materials

Zum Schweißen stabilisierter und nichtstabilisierter nichtrostender Cr-Ni-Mo-Stähle und Cr-Ni-Stähle, z.B. 1.4401, 1.4404, 1.4571, sowie 1.4301, 1.4306, 1.4541, 1.4550, für Betriebstemperaturen bis 400° C. Auch für Stähle mit max. 19% Chrom.

Resistance against corrosion

Good resistance to general and, owing to low C content, intergranular corrosion. The Mo content gives good resistance also to pitting.

Application notes from page 88.

Properties approx. values

Yield strength $R_{p0,2}$ [MPa]	400 (20 °C); 290 (400 °C)
Tensile strength R_m [MPa]	610 (20 °C); 440 (400 °C)
Elongation A [%]	37 (20 °C); 29 (400 °C)
Reduction of area [%]	68
Notched impact strengthV [J]	130 (20 °C); 50 (–196 °C)
Hardness [Vickers]	160
Heat conductivity at temperature °Celsius	20; 100; 300; 500
Heat conductivity [W/m °C]	15; 16; 19; 21
Thermal expansion per °C, from 20°C - 400°C	$18 \cdot 10^{-6}$
Density [g/cm³]	7,9

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	MIG: Ar+1-3% O_2, Ar+1-3% CO_2, Ar+He+O_2, Ar+He+CO_2, Ar+He+CO_2+H_2 TIG: Ar, He, Ar+He, Ar+2-5% H_2
Polarity	MIG = +, TIG = –
Approvals	TÜV, DB

Dimensions and packaging

MIG wire Ø [mm] 0,8 1,0 1,2 1,6

TIG rod Ø [mm] 1,0 1,2 1,6 2,0 2,4 3,2 4,0

Wire electrodes	Packaging unit
BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Drums	Packaging unit
ECO-drum / 250 kg	2 drums = 500 kg (Pallet)

Current data sheet and stock level
migal.co/en/products/stainless-steel-welding-wire/4430-316lsi-ml-19123-lsi

ML 22.9.3 NL 1.4462 · 2209.

Stainless steel wire electrodes/welding rods

Typical composition of the filler metal in %

C	Si	Mn	P	S	Cr	Ni	Mo	N
≤ 0,020	0,50	1,60	≤ 0,020	≤ 0,015	23,00	9,00	3,20	0,16

Classification

EN ISO 14343-A/G	22 9 3 N L
DIN 8556	1.4462
AWS ER	2209

Base materials

For welding stainless duplex steels, e.g. 1.4417, 1.4462 and 1.4362.

Resistance against corrosion

Good resistance to general and, owing to low C content, intergranular corrosion. The Mo content gives good resistance also to pitting.

Application notes from page 88.

Properties approx. values

Yield strength $R_{p0,2}$ [MPa]	600 (20 °C); 420 (300 °C)
Tensile strength R_m [MPa]	750 (20 °C); 600 (300 °C)
Elongation A [%]	25 (20 °C); 20 (300 °C)
Notched impact strengthV [J]	130 (20 °C); 50 (–196 °C)
Hardness [Vickers]	240
Heat conductivity [W/m °C]	16
Thermal expansion per °C, from 20°C - 400°C	$14,5 \cdot 10^{-6}$
Density [g/cm³]	7,9

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	MIG: Ar+1-3% O_2, Ar+1-3% CO_2, Ar+He+O_2, Ar+He+CO_2, Ar+He+CO_2+H_2 TIG: Ar, He, Ar+He, Ar+2-5% H_2
Polarity	MIG = +, TIG = –
Approvals	TÜV

Dimensions and packaging

MIG wire Ø [mm]: 0,8 | 1,0 | 1,2 | 1,6

TIG rod Ø [mm]: 1,0 | 1,2 | 1,6 | 2,0 | 2,4 | 3,2 | 4,0

Wire electrodes	Packaging unit
BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Drums	Packaging unit
ECO-drum / 250 kg	2 drums = 500 kg (Pallet)

Stainless materials › Data sheet

ML 19.12.3 NbSi 1.4576 · 318Si.

Stainless steel wire electrodes/welding rods

Typical composition of the filler metal in %

C	Si	Mn	P	S	Cr	Ni	Mo	Nb	Co	Cu	N
0,04	0,90	1,20	≤ 0,025	≤ 0,015	18,50	12,50	2,60	≥ 12xC ≤ 0,6	≤ 0,20	≤ 0,20	0,065

Classification

EN ISO 14343-A/G	19 12 3 NbSi
DIN 8556	1.4576
AWS ER	318Si

Base materials

Zum Schweißen stabilisierter und nichtstabilisierter nichtrostender Cr-Ni-Mo-Stähle und Cr-Ni-Stähle, z.B. 1.4401, 1.4404, 1.4571, sowie 1.4301, 1.4306, 1.4541, 1.4550, für Betriebstemperaturen bis 400° C.

Resistance against corrosion

Good resistance to general and, owing to Nb content, low intergranular corrosion. The Mo content gives good resistance also to pitting.

Application notes from page 88.

Properties approx. values

Yield strength $R_{p0,2}$ [MPa]	400 (20 °C); 390 (400 °C)
Tensile strength R_m [MPa]	610 (20 °C); 540 (400 °C)
Elongation A [%]	35 (20 °C); 30 (400 °C)
Reduction of area [%]	60
Notched impact strengthV [J]	110 (20 °C); 40 (–196 °C)
Hardness [Vickers]	160
Heat conductivity at temperature °Celsius	20; 100; 300; 500
Heat conductivity [W/m °C]	15; 16; 21; 23
Thermal expansion per °C, from 20°C - 400°C	$18 \cdot 10^{-6}$
Density [g/cm³]	8,0

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	MIG: Ar+1-3% O_2, Ar+1-3% CO_2, Ar+He+O_2, Ar+He+CO_2, Ar+He+CO_2+H_2 TIG: Ar, He, Ar+He, Ar+2-5% H_2
Polarity	MIG = +, TIG = –
Approvals	TÜV, DB

Dimensions and packaging

MIG wire Ø [mm]: 0,8 | 1,0 | 1,2 | 1,6

TIG rod Ø [mm]: 1,0 | 1,2 | 1,6 | 2,0 | 2,4 | 3,2 | 4,0

Wire electrodes	Packaging unit
BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Drums	Packaging unit
ECO-drum / 250 kg	2 drums = 500 kg (Pallet)

Current data sheet and stock level
migal.co/en/products/stainless-steel-welding-wire/4576-318si-ml-19123-nbsi

ML 25.20 1.4842 · 310.

Stainless steel wire electrodes/welding rods

Typical composition of the filler metal in %

C	Si	Mn	P	S	Cr	Ni	Mo	Cu
0,12	0,40	1,80	≤ 0,025	≤ 0,015	26,00	20,70	≤ 0,50	≤ 0,40

Classification

EN ISO 14343-A/G	25.20
DIN 8556	1.4842
AWS ER	310

Base materials

Auftragsschweißungen und Verbindungen an artgleichen/artähnlichen hitzebeständigen Stählen/Stahlguß.

Resistance against corrosion

Zunderbeständig bis 1050° Celsius.

Application notes from page 88.

Properties approx. values

Yield strength $R_{p0,2}$ [MPa]	320
Tensile strength R_m [MPa]	550
Elongation A [%]	25
Notched impact strengthV [J]	80

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	MIG: Ar+1-3% O_2, Ar+1-3% CO_2, Ar+He+O_2, Ar+He+CO_2, Ar+He+CO_2+H_2 TIG: Ar, He, Ar+He, Ar+2-5% H_2
Polarity	MIG = +, TIG = –

Dimensions and packaging

MIG wire Ø [mm] 0,8 1,0 1,2 1,6

TIG rod Ø [mm] 1,0 1,2 1,6 2,0 2,4 3,2 4,0

Wire electrodes	Packaging unit
BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Drums	Packaging unit
ECO-drum / 250 kg	2 drums = 500 kg (Pallet)

What makes stainless steel stainless.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHAT MAKES A STEEL STAINLESS?

> Chromium. From about 10.5 % chromium, the steel spontaneously forms an extremely thin layer of chromium oxide in air, the passive layer. It is only a few nanometres thick and invisible, yet it protects the steel against many media. If it is damaged, it grows back by itself as long as oxygen reaches the surface.

Nickel, molybdenum, nitrogen, titanium and niobium further improve corrosion resistance and determine microstructure and strength. Stainless steels are standardised in EN 10088.

For welding, this leads to the most important principle of this series: the weld is only as resistant as its surface. Anything that disturbs the passive layer or lowers the chromium content at the surface makes the steel vulnerable at that point.

When does stainless steel rust after all?

When the passive layer cannot form, or cannot form completely. This happens when oxygen is lacking or when too little chromium is available at the surface.

- **No oxygen:** In narrow gaps, under washers, under deposits or in stagnant liquid, the passive layer does not renew itself. If a corrosive medium penetrates, crevice corrosion begins.
- **Foreign iron:** Grinding dust and particles of carbon steel, for example from tools, brushes or supports, rust themselves and prevent the passive layer from forming underneath. The result is rust spots on stainless steel, known as extraneous rust.
- **Temper colours and scale:** The coloured oxide layers next to the weld are thicker than the passive layer but not protective, and the surface underneath is depleted of chromium. They must be removed, see Temper colours, pickling, passivation (page 96).
- **Chromium carbides:** If a steel with too much carbon remains too long in the range of about 450 to 850 °C, the carbon binds chromium at the grain boundaries. Next to them, the chromium content falls below the necessary limit and the steel becomes susceptible to intergranular corrosion.
- **Chlorides:** Salt water, road salt and chloride-containing cleaning agents attack the passive layer locally. Pitting corrosion results, and with warm media and tensile stress also stress corrosion cracking.

The four groups of steels

By microstructure, a distinction is made between austenitic, ferritic, austenitic-ferritic (duplex) and martensitic steels. Welded components almost always use austenitic steels, increasingly also duplex and ferritic grades.

Group	Typical grades	Magnetic	In welding
Austenitic	chromium-nickel(-molybdenum) steels, e.g. 1.4301, 1.4307, 1.4404, 1.4571	no (annealed)	readily weldable; high distortion, fully austenitic grades prone to hot cracking
Ferritic	chromium steels with little or no nickel, e.g. 1.4003, 1.4016, 1.4512	ja	grain coarsening in the heat-affected zone, above about 6 mm wall thickness only conditionally weldable
Austenitic-ferritic (duplex)	z. B. 1.4362, 1.4462, 1.4410	ja	readily weldable with controlled heat input; keep ferrite and austenite contents in balance
Martensitic	hardenable chromium steels, e.g. for knives, shafts, turbine parts	ja	hardens on cooling, risk of hardening cracks; only with preheating and heat treatment

The microstructure that forms in the weld metal depends on the ratio of the ferrite-forming elements (chromium, molybdenum, silicon, niobium) to the austenite-forming ones (nickel, carbon, manganese, nitrogen). It can be estimated with the Schaeffler diagram; more on this in Microstructure, delta ferrite and hot cracking (page 89) and in the calculator for the Schaeffler, DeLong and WRC diagrams.

Also in the full article on migal.co: Material number, steel name, AISI: how to read the designations · What makes stainless steel different in welding · Why L grades or stabilised steels for welded parts · How resistant is which steel? The PREN · Which wire for which steel

Full article on migal.co
migal.co/en/service/welding-of-stainless-steel/stainless-steel-basics

Delta ferrite and hot cracking.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHY DOES AUSTENITIC WELD METAL NEED FERRITE?

Because a small proportion of delta ferrite protects against hot cracks. Weld metal that solidifies fully austenitic cracks easily while it is still liquid or mushy between the grains. This is why most filler metals for austenitic steels are alloyed so that a few per cent of ferrite remain in the weld metal, typically around 5 %.

The cracks are caused by accompanying elements, above all sulphur and phosphorus. They are hardly soluble in austenite, accumulate in the residual melt between the dendrites and form low-melting films there. Nickel sulphide, for example, melts at around 645 °C. As the weld cools, it contracts and the grain boundaries tear open.

Ferrite absorbs sulphur and phosphorus much better and interrupts the continuous grain boundaries. If the weld metal solidifies as ferrite first, the residual melt stays cleaner and hot cracks become rare. This intended ferrite content can be recognised by the slight magnetism of a stainless steel weld.

Solidification mode and susceptibility to hot cracking

What matters is the phase with which the weld metal starts to solidify. Susceptibility to hot cracking decreases markedly from fully austenitic to fully ferritic solidification.

Solidification mode	Sequence	Ferrite in the weld metal	Susceptibility to hot cracking
A	fully austenitic	no ferrite	highest
AF	austenite first, ferrite between the dendrites	little, usually below 3 FN	high
FA	ferrite first, most of which transforms into austenite	about 3 to 15 FN	low
F	fully ferritic, austenite forms only in the solid state	high, e.g. duplex	lowest

Ferrite number and solidification mode both depend on the composition, but not always unambiguously. In practice, the ferrite number is nevertheless specified and measured, because it is standardised and easy to check.

Order of the solidification modes according to ISO 3581, Annex B. The FN ranges are guide values.

There are two kinds of hot cracks. **Solidification cracks** form in the weld metal itself, usually along the weld centreline or in the end crater. **Liquation cracks** form in the heat-affected zone or in the underlying bead when the next pass remelts the low-melting grain boundaries. The mechanism is the same in both cases.

Ferrite number or per cent?

The ferrite number (FN) is a standardised characteristic value measured magnetically according to ISO 8249, not a volume fraction. At low contents, FN and per cent ferrite are close together; as ferrite increases, the FN is noticeably higher. Anyone who equates FN with per cent overestimates the ferrite content.

In the past, ferrite was counted in the metallographic section. Because it is very fine, irregular and unevenly distributed, the results scattered widely. A common scale was therefore agreed: measuring instruments are calibrated with standards to which a ferrite number is assigned. In round-robin tests, different laboratories determine the same specimen to within about ± 1 FN, in the range from 0 to 28 FN.

For duplex steels, the scale extends to 100 FN. For his range of 0 to 18 FN, DeLong gives about 0 to 14 % ferrite.

How is the ferrite content measured?

With a magnetic measuring instrument calibrated according to ISO 8249. Measurements are taken at a smoothed spot in the middle of the weld, not at edges, on rough ripples or next to magnetic base material.

Within a weld, the ferrite content varies naturally: where beads overlap, the next pass anneals the previous one and lowers the ferrite. Individual values are therefore less meaningful than the mean of several measurements. Curved surfaces and thin sheet distort the result.

Procedure and assessment are described in Testing, health and safety (page 100).

Also in the full article on migal.co: Schaeffler, DeLong, WRC: which diagram for what · What changes the ferrite content in the weld · How much ferrite is right · Avoiding hot cracks

Selecting the filler metal.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

THE BASIC RULE: MATCHING OR SLIGHTLY HIGHER ALLOYED

> For stainless steels, a matching or similar filler metal is normally used, i.e. a wire with about the same composition as the base material. It is balanced so that the weld metal contains some delta ferrite and is just as corrosion-resistant as the sheet.

Over-alloyed fillers are special cases: when the weld is to be more resistant than the base material, when different materials are joined, or to simplify stockholding. A molybdenum-alloyed wire such as 316LSi is also suitable for molybdenum-free steels such as 1.4301 and 1.4541. The reverse does not work: 308LSi on 1.4404 produces a weld without molybdenum that is weaker against chlorides than the sheet.

Besides the composition, required approvals, service temperature, wall thickness and welding position also play a part. For pressure equipment or construction, an approval of the wire may be mandatory.

Which filler for which steel?

The assignment of common steels according to DVS 0931. For the standard grades 1.4301 and 1.4404, 308LSi and 316LSi are the wires most frequently needed.

Base material	ISO 14343-A	AWS A5.9	MIGAL
1.4301, 1.4306, 1.4307, 1.4311	19 9 L (Si)	ER308L(Si)	308LSi
1.4541, 1.4550	19 9 Nb or 19 9 L	ER347 / ER308L	308LSi
1.4401, 1.4404, 1.4406, 1.4435, 1.4436	19 12 3 L (Si)	ER316L(Si)	316LSi
1.4571, 1.4580	19 12 3 Nb or 19 12 3 L	ER318 / ER316L	318Si, 316LSi
1.4438, 1.4439	18 16 5 N L	ER317LN	–
1.4539	20 25 5 Cu L	ER385	–
1.4529	nickel base Ni 6625	ERNiCrMo-3	NiCr21Mo9Nb
1.4362, 1.4462	22 9 3 N L	ER2209	2209
1.4410, 1.4501	25 9 4 N L	–	–
1.4003	19 9 L Si	ER308LSi	308LSi
1.4016, 1.4113	17 or austenitic	ER430	–
1.4509, 1.4511, 1.4512	18 L Nb, 13 L Nb or austenitic	ER430LNb, ER409Cb	–
1.4828 (heat-resistant)	22 12 H	ER309	–
1.4841, 1.4845 (heat-resistant)	25 20	ER310	310

According to DVS 0931, Tables 1a to 1d, simplified; “(Si)” means with or without increased silicon content. For 1.4539 under increased corrosive load, clarify the molybdenum content of the weld metal. For duplex steels, see also DVS 0946.

All wires: stainless steel welding wire and nickel welding wire.

G 19 12 3 L Si, SS316LSi, ER316LSi: reading the designations

A stainless steel wire usually has three names: according to ISO 14343 system A (European, by composition), according to system B (by alloy type, as in the American standards) and according to AWS A5.9. Often they all stand for the same alloy.

System A, for example *ISO 14343-A – G 19 12 3 L Si*:

- **G** = wire electrode for gas metal arc welding. For other processes, the letter is W (TIG), P (plasma), S (submerged arc), B (strip electrode) or L (laser).
- **19 12 3** = nominal contents: around 19 % chromium, 12 % nickel, 3 % molybdenum.
- **L** = low carbon, a maximum of 0.03 %.
- **Si** = increased silicon content of 0.65 to 1.2 % instead of a maximum of 0.65 %.
- Other symbols: **Nb** = niobium-stabilised, **N** = with nitrogen, **Mn** = with increased manganese, **H** = higher carbon for high temperatures, **Z** = alloy not listed in the standard table.

System B, for example *ISO 14343-B – SS316LSi*: the first S stands for solid wire, the second for stainless steel. There is no letter for the process; the same name applies to MIG/MAG wire and TIG rod. According to AWS A5.9, the wire is called *ER316LSi*.

The ranges of the two systems do not match exactly. A wire may carry both designations if its analysis falls within both sets of limits. Covered electrodes are standardised in ISO 3581 (e.g. E 19 12 3 L R), tubular cored electrodes in ISO 17633 (e.g. T 19 12 3 L P M).

Also in the full article on migal.co: L grade or stabilised · With or without Si · Ferritic steels: usually welded with austenitic filler · Duplex, dissimilar joints, high-alloy grades · Diameter and packaging

Full article on migal.co
migal.co/en/service/welding-of-stainless-steel/filler-metal

Welding process.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHICH PROCESSES ARE THERE FOR STAINLESS STEELS?

> Almost all of those known from carbon steel. Austenitic and ferritic stainless steels can be joined with the same fusion and pressure welding processes and the same equipment as unalloyed steels. Only oxy-fuel gas welding is out of the question.

In production, MAG welding with solid or flux-cored wire and TIG welding dominate. Plasma and laser beam welding are the mechanised processes for high volumes, manual metal arc welding has its place on site, and submerged arc welding for thick plate.

Process (ISO 4063)	Typical range	Strengths	Limits
MAG with solid wire (135)	thin to thick plate, workshop and robot	high deposition rate, easy to mechanise, with pulsed arc also thin sheet and positional welding	gas with little O_2 or CO_2 required; short arc spatters
MAG with flux-cored wire (136, 138)	medium and large wall thicknesses	little spatter, flat seams; rutile flux-cored wire for positional welding, metal-cored wire for multi-pass robot welding	remove slag (136); 4-roll drive
TIG (141, without filler 142)	thin sheet, pipes, root passes	highest weld quality, all positions, very clean, no spatter	slow, low deposition rate
Plasma (15)	microplasma up to 1 mm, keyhole up to about 10 mm in a square butt joint	fast, narrow seam and heat-affected zone, little distortion	precise joint preparation, fixture and travel carriage required
Manual metal arc (111)	site work, assembly, repair	simple equipment, outdoors, all positions, little heat per bead	slow, slag, keep electrodes dry
Laser beam (52)	fibre laser about 0.2 to 4 mm, CO_2 laser up to about 15 mm	very narrow seam, hardly any distortion, fast, easy to automate	tight gaps, precise edges; duplex: little austenite
Submerged arc (12)	thick plate, long seams	very high deposition rate, smooth seams	flat and horizontal position only, high heat input

Guide values according to ISER information sheet 823 (2019) and DVS 0931. The limits depend on material, joint shape and equipment.

MAG welding: the workhorse

In gas metal arc welding of stainless steels, almost exclusively MAG is used, with an argon-rich gas containing only a little oxygen or CO_2. More CO_2 brings carbon into the weld metal and reduces the resistance to intergranular corrosion.

Welding is done with direct current, wire electrode positive, with wires from 0.8 to 1.6 mm. The type of arc is chosen according to the task:

- **Spray arc** for the flat and horizontal positions: fine droplets, no short circuits, hardly any spatter, high output.
- **Short arc** for thin sheet, root passes and positional welding when little heat is required. Drawbacks: firmly adhering spatter and an excessively convex bead.
- **Pulsed arc**: little heat with a calm, low-spatter metal transfer. It can be used to weld thin sheet as well as thick plate, also in positional welding. For stainless steels it is often the best choice.

For torch guidance, DVS 0931 recommends:

- Keep the arc as short as possible. A long arc burns off more chromium and picks up nitrogen from the air, which lowers the ferrite content.
- Guide solid wire slightly pushing to neutral, with the shortest possible wire stick-out. This improves wetting and penetration.
- Weld metal-cored wire with up to 5 mm longer stick-out, slag-forming flux-cored wire slightly dragging and in the spray arc.

The suitable gases are shown in Shielding gases (page 92), the choice of wire in Choosing the filler metal (page 90).

Also in the full article on migal.co: Flux-cored wire: solid wire or flux-cored wire · TIG welding: for thin sheet, pipes and roots · Plasma welding: fast and narrow · Manual metal arc welding: on site · Laser beam welding: narrow, fast, low distortion · Submerged arc welding: for thick plate · Which process for which task

Shielding gases.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHY STAINLESS STEEL NEEDS ITS OWN SHIELDING GAS

Because carbon and oxygen from the gas reduce the corrosion resistance of the weld. In MAG welding of stainless steels, argon with only a few per cent of CO_2 or O_2 is therefore used, not the usual mixed gas for carbon steel.

But MAG welding does not work entirely without active components either: a little CO_2 or O_2 stabilises the arc and improves the flow of the weld pool. The limits are narrow:

- **CO_2** releases carbon into the weld metal. Up to about 3 %, DVS 0931 generally regards this as uncritical. More CO_2 can make the weld metal susceptible to intergranular corrosion, especially with L grades, see What makes stainless steel stainless (page 88).
- **Oxygen** brings no carbon but oxidises the weld. Higher contents such as 8 % are metallurgically harmless but leave a heavily oxidised surface that has to be reworked.
- Both shift the microstructure towards austenite: O_2 through burn-off of chromium, CO_2 through carbon. This lowers the ferrite content, see Microstructure, delta ferrite and hot cracking (page 89).

The gas groups according to ISO 14175

In ISO 14175, shielding gases are divided into groups according to their components. For stainless steels, the most important are the inert gases (I), the weakly oxidising mixed gases of group M1, the reducing Ar-H_2 mixtures (R) and the nitrogen-containing gases (N).

Group	Composition	Use with stainless steel
I1	Argon	TIG, plasma, root protection; all materials
I3	Argon + 0.5 to 95 % helium	TIG, MIG; more energy and penetration
M12	Argon + 0.5 to 5 % CO_2	MAG with solid and metal-cored wire
M13	Argon + 0.5 to 3 % O_2	MAG with solid and metal-cored wire
M11, M14	as M12, additionally H_2 (M11) or O_2 (M14)	MAG, special mixtures
M21	Argon + 15 to 25 % CO_2	slag-forming flux-cored wire
R1	Argon + 0.5 to 15 % H_2	TIG and plasma on austenitic grades, root protection
N2	Argon + 0.5 to 5 % N_2	TIG on duplex, root protection
N5	Nitrogen + 0.5 to 50 % H_2 (“forming gas”)	root protection

Groups according to ISO 14175:2008, Table 2. In the M groups, argon may be replaced wholly or partly by helium. For welds subject to acceptance, the combination of wire and gas must be approved.

MAG with solid wire and metal-cored wire

Gases of group M1 have proven themselves: argon with 1 to 3 % O_2 (M13) or with up to 2.5 % CO_2 (M12), also as a three-component gas with both (M14). Metal-cored wire needs the same gases as solid wire.

- **Helium** in place of part of the argon makes the weld pool more fluid and improves penetration. This helps with thicker plates and higher speeds.
- **Hydrogen** in small amounts (M11) is only an option for austenitic steels, never for ferritic and duplex steels.
- For **nickel-base filler metals**, inert gases or multi-component gases with helium or hydrogen are used, some with only about 0.05 % CO_2 for stabilisation. Here the manufacturers’ recommendations apply.

Slag-forming flux-cored wire: normal mixed gas

Slag-forming flux-cored wires for stainless steel are welded with the same gases as flux-cored wire for carbon steel, preferably with argon and 15 to 25 % CO_2 (M21), also with pure CO_2.

The flux filling is formulated so that the weld metal does not pick up harmful carbon even at high CO_2 contents. That is the difference from solid wire, for which these gases are unsuitable.

Also in the full article on migal.co: TIG and plasma: argon, helium, hydrogen, nitrogen · Which gas for which material · Good gas shielding in practice

Full article on migal.co
migal.co/en/service/welding-of-stainless-steel/shielding-gases

Heat input.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHY STAINLESS STEEL TOLERATES LITTLE HEAT

> Austenitic steels conduct heat poorly and expand a great deal. The heat stays at the weld, and the component distorts more than carbon steel. The rule is therefore: limit the heat input, keep to the interpass temperature, and as a rule do not preheat.

According to DVS 0931, too much heat can lead to the following damage, depending on the material:

- more distortion and residual stresses,
- undesirable precipitates such as carbides or sigma phase,
- coarse grain and loss of toughness in the heat-affected zone,
- hot cracks, especially in fully austenitic steels,
- higher susceptibility to intergranular corrosion,
- more oxidation and temper colours.

The material properties compared are given in What makes stainless steel stainless (page 88), the causes of hot cracks in Microstructure, delta ferrite and hot cracking (page 89).

Calculating arc energy and heat input

The arc energy is the electrical power of the arc per centimetre of weld. The heat input is the part of it that actually goes into the component. To obtain it, the arc energy is multiplied by the thermal efficiency of the process.

Arc energy E [kJ/cm] = U [V] · I [A] · 60 / (v [cm/min] · 1000)

Heat input Q [kJ/cm] = k · E

For gas metal arc welding, DVS 0931 assumes an efficiency of k = 0.8. In TIG welding it is considerably lower, about 0.6 according to EN 1011-1. For manual metal arc welding it is also 0.8, for submerged arc 1.0.

MAG example: 24 V, 180 A, 30 cm/min gives E = 24 · 180 · 60 / (30 · 1000) = 8.6 kJ/cm and Q = 0.8 · 8.6 ≈ 6.9 kJ/cm.

This can be calculated with the Heat input calculator.

- weld faster,
- reduce current and voltage,
- use thinner wire, for example for vertical-up welds,
- stringer beads instead of wide weave passes, more passes with a smaller cross-section.

Duplex: neither too much nor too little

Duplex steels have a heat window. If the heat is too low, the weld cools too quickly, too little austenite forms, and toughness and corrosion resistance drop. If it is too high, sigma phase and other intermetallic precipitates are a risk.

- **Arc energy according to DVS 0946:** duplex 5 to 25 kJ/cm, super duplex 2 to 15 kJ/cm.
- **Austenite content in the weld metal:** 30 to 70 % if no solution annealing is carried out.
- **Nitrogen** in the steel and in the shielding gas promotes the formation of austenite. Modern duplex steels usually contain over 0.15 % N and therefore hardly need preheating. According to the ISER information sheet, there is hardly any risk of too little austenite with the usual arc processes.
- **Plan the welding sequence** so that the parts can cool between passes.

The cooling time can be estimated with the t8/5 cooling time calculator. More on the gases and the microstructure in Duplex and super duplex (page 97).

Limiting distortion

Above all, little heat and short tack spacings help against distortion.

- weld with low arc energy,
- dissipate heat via copper bars, which also support the root,
- weld in fixtures,
- tack more closely than with carbon steel,
- weld symmetrically and with backstep welding so that the stresses balance out.

Tack spacings by sheet thickness: Joint preparation and tack welding (page 94).

Heat treatment after welding

Austenitic welded joints are generally not heat-treated, because undesirable precipitates can form during annealing.

For duplex steels, only solution annealing comes into question, if at all. According to DVS 0946, this is done at 1020 to 1050 °C with a holding time of 5 minutes after through-heating, followed by quenching in water. For ferritic and martensitic steels, the heat treatment depends on the material and filler metal.

Also in the full article on migal.co: Preheating and interpass temperature

Joint preparation and tacking.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

CLEANLINESS DETERMINES CORROSION RESISTANCE

With stainless steel, the corrosion resistance of the weld begins before the arc is struck. Joint faces and their surroundings must be bright metal and free of grease, oil, paint, scale and iron particles.

- **Separate tools:** use grinding discs, brushes and files only for stainless steels, never alternately for carbon steel. Iron particles on the surface become extraneous rust and can trigger pitting corrosion.
- **Stainless steel brushes** that have not previously been used on any other material.
- **Remove grease and oil:** organic residues can carburise the weld metal and form inclusions.
- **No chlorinated cleaners:** solvents based on chlorinated hydrocarbons form the highly toxic phosgene under the UV radiation of the arc. DVS 0931 names acetone as an alternative.
- **Clamping fixtures** in contact with the workpiece made of stainless steel or heat-resistant plastic, never of unalloyed steel.

Preparing the joint faces

The grooves are produced mechanically or thermally. Thermally cut edges must be freed of oxide before welding.

- **Mechanically:** shearing, planing, milling, grinding or water jet cutting.
- **Thermally:** plasma or laser beam cutting. The cut edges are usually lightly ground over, because adhering oxides reduce the corrosion resistance of the weld.
- **Abrasives:** resin-bonded corundum discs, free of iron and sulphur, with fine grit, used only for stainless steels.

Joint shapes and gaps

Joint shapes follow ISO 9692-1. There are deviations for duplex and for the beam processes.

Case	Recommendation
Joint shape in general	according to ISO 9692-1, depending on workpiece thickness and process
Duplex, super duplex	larger groove angle, 70 to 80° instead of 60°, against lack of fusion in the viscous weld pool
Plasma, keyhole technique	square butt joint without gap up to about 10 mm; thicker as Y groove with about 5 mm root face; gap over 0.08 × sheet thickness requires filler metal
Laser without filler metal	gap at most 1/10 of the sheet thickness, with thick sheets at most half the focus diameter; larger gaps only with filler wire

According to DVS 0931, DVS 0946 and ISER information sheet 823 (2019). When heated, duplex steels expand less than austenitic and more than ferritic grades. This must be taken into account for the gap width when tacking.

The processes in detail: Processes at a glance (page 91).

Tack spacing by sheet thickness

Austenitic steels must be tacked more closely than carbon steel. When heated, they expand around a third more and conduct heat only about a third as well.

Thickness	Spacing of tack welds
1 to 1.5 mm	20 to 40 mm
2 to 3 mm	50 to 70 mm
4 to 6 mm	70 to 100 mm
over 6 mm	100 to 150 mm

Recommendation according to ISER information sheet 823 (2019), paraphrased. DVS 0931 gives a coarser 10 to 100 mm for sheets up to about 3 mm and 80 to 200 mm above. Tack duplex more closely because of its higher strength.

Further measures against distortion: Heat input and interpass temperature (page 93).

Weld pool backing

As a rule, stainless steel is welded without weld pool backing, using backing gas instead of a backing bar.

The exception according to DVS 0931 is the root with slag-forming flux-cored wire. Here a ceramic backing is recommended.

Also in the full article on migal.co: Tack welding correctly

Full article on migal.co
migal.co/en/service/welding-of-stainless-steel

Root protection and purging.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHY THE ROOT MUST BE PROTECTED

On the reverse side of the weld, the hot metal is in contact with air. Without shielding gas, temper colours and scale form there, and the corrosion resistance drops. In purging, the air at the root is replaced by a backing gas.

WHICH BACKING GAS FOR WHICH MATERIAL?

Gas	ISO 14175	Behaviour	Compared with air	Suitable for
Argon	I1	inert	heavier	all materials, including ferritic chromium steels, duplex, titanium
Nitrogen	N1	largely inert	lighter	austenitic steels, duplex
Argon-hydrogen	R1	reducing	heavier	austenitic steels, nickel and nickel alloys
Nitrogen-hydrogen (“forming gas”)	N5	reducing	lighter	austenitic steels, nickel and nickel alloys, duplex only to a limited extent

This is particularly important where the root can no longer be reached later, for example in pipelines. There, temper colours can be neither ground off nor pickled. According to DVS 0931, the root must then be protected in MAG welding too. In multi-pass welds, it is advisable to maintain the protection beyond the root pass, because the following passes heat the root up again.

Not every temper colour is equally harmful: yellow reduces the resistance only slightly, red and grey considerably. Because there is always a temperature gradient during welding, blue is practically always accompanied by red. More on this in Temper colours, pickling, passivation (page 96).

Strictly speaking, “forming gas” refers only to the mixture of nitrogen and hydrogen. The general term is backing gas.

Which backing gas for which material?

Argon always works. Nitrogen and hydrogen-containing gases are cheaper or protect better, but are not suitable for every material.

Summarised from DVS 0937 and DVS 0931. The hydrogen content of backing gases is at most 25 %.

- **Hydrogen** binds oxygen and therefore protects better against temper colours than a gas without hydrogen. It is unsuitable for gas-sensitive materials such as titanium and for fine-grained structural steels with a yield strength of 420 MPa and above. For ferritic and martensitic steels it is suitable only to a limited extent.
- **Duplex** can advantageously be purged with nitrogen-containing gas, which improves toughness and corrosion resistance. Hydrogen-containing gases are possible only with at most 10 % H_2, preferably 5 %, and only without a gap, so that no hydrogen gets into the arc.
- **Titanium-stabilised steels** such as 1.4571 acquire a golden-yellow layer of titanium nitride on the root with nitrogen-containing gas. It lies only on the weld, not next to it, which distinguishes it from a temper colour. No influence on corrosion resistance is known. If discolouration-free welds are required, use argon or argon-hydrogen here.
- **Costs:** if argon from a tank is available via a ring main anyway, there is nothing against using it for purging as well, as long as it suits the material.

The shielding gases for the arc: Shielding gases (page 92).

How long to pre-purge?

For pipelines, DVS 0937 gives a formula as a first guide. It depends on the inside diameter, the purge length, the gas flow rate and the target residual oxygen.

$$t\,[s] = 6 \cdot \pi \cdot d_i^2\,[mm] \cdot l\,[m] \,/\, (400 \cdot Q\,[l/min]) \cdot k$$

The factor k is 5.3 for 1000 ppm, 7.6 for 100 ppm, 8.3 for 50 ppm, 8.6 for 30 ppm and 10 for 10 ppm. It states how many pipe volumes of gas must flow through.

Example: pipe with 50 mm inside diameter, 2 m purge length, 10 l/min, target 100 ppm: around 3 minutes and just under 30 l of gas.

You can calculate this with the Purge time calculator.

The formula is a starting value for your own trials. Only a measurement shows whether the residual oxygen has really been reached. In series production, the proven procedure can also be demonstrated on a test piece and recorded in the welding procedure specification.

Also in the full article on migal.co: Purging correctly · Purging devices · Measuring residual oxygen · Hoses and lines · Purging safely

Temper colours.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHAT TEMPER COLOURS ARE

> Temper colours are thin oxide layers that form next to the weld during welding. They form when hot metal comes into contact with oxygen. The chromium in these layers is then missing in the steel beneath, and the corrosion resistance drops there.

At room temperature, stainless steel protects itself: a passive layer of chromium oxide only a few nanometres thin forms again and again in air, see What makes stainless steel stainless (page 88). Under welding heat, by contrast, oxidation proceeds faster and deeper. The layer becomes thicker, changes its composition and loses its protective effect.

The colour comes from light refracted at the oxide layer. The further away from the weld pool, the thinner the layer. From the weld outwards there follow roughly **grey, blue, red, yellow** and finally bright metal, with smooth transitions. The colour depends not only on the temperature, but also on how long the heat acts and how much oxygen is present.

Which colours are harmful

Yellow reduces corrosion resistance slightly, red and grey considerably. Because every blue discolouration is accompanied by a red one, the practical rule is: anything darker than yellow must go if the weld is exposed to corrosion.

Colour	Effect on corrosion resistance
Straw yellow to yellow	only a slight reduction in resistance; the only colour that also occurs on its own
Dark yellow to red	from darker than reddish yellow, susceptibility to pitting rises sharply
Blue	in itself more resistant again, but never occurs alone: there is always red next to it
Grey, black, scaled	resistance severely impaired; the chromium here is literally burnt

According to DVS 0937 and Warzawa (DVS-Berichte vol. 275). In the salt spray test, the resistance to pitting decreases steadily as the yellow becomes darker.

In addition, with prolonged heating the chromium in the microstructure can redistribute. If it falls locally below about 12 %, the steel is no longer stainless there.

Avoiding temper colours

The simplest approach is not to let temper colours form in the first place. To achieve this, oxygen must be kept away from the hot surface.

- **Purge the root side:** Root protection and purging (page 95).
- **Weld the face side with good gas shielding,** if necessary with a trailing gas shield that covers the cooling weld afterwards: Shielding gases (page 92).
- **Keep the heat input low:** the shorter the time the metal is hot, the thinner the oxide layer, see Heat input and interpass temperature (page 93).
- **Dry, tight gas lines:** moisture in the gas also produces temper colours.

Assessing temper colours

Which temper colour is still acceptable should be specified before welding, for example in the order or in the welding procedure specification. It is then checked by comparison with colour charts or reference samples.

- **The same oxidation gives the same colour,** regardless of the base material. This is why temper colours can be compared with neutral colour charts.
- **Light and observer** influence the judgement: brightness, light colour, experience and colour vision. It is best to record the viewing conditions in the test report.
- **Through an endoscope** colours look different. Here it helps to view reference surfaces first through the endoscope and then directly.
- **Rough surfaces** and printed colour charts render colours differently from smooth steel.

Passivation

After pickling and rinsing, the passive layer forms by itself in air. Depending on the surface, this can take several hours. Additional passivation is carried out if this time is not available or high requirements apply.

According to the ISER information sheet, a treatment in nitric acid of about 20 % can be used for this. Here too, the part is then rinsed thoroughly with water.

Also in the full article on migal.co: Removing temper colours · Pickling in practice

Full article on migal.co
migal.co/en/service/welding-of-stainless-steel/temper-colours

Duplex and super duplex.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHAT MAKES DUPLEX STEEL SPECIAL

Duplex steels consist of roughly half ferrite and half austenite. The austenite provides toughness and general corrosion resistance, the ferrite strength and resistance to stress corrosion cracking. In welding, the key is to preserve this balance.

In the delivery condition, the microstructure is set by solution annealing at 1020 to 1100 °C and rapid cooling: a ferritic matrix with about 45 to 60 % austenite. Compared with austenitic steels, duplex steels offer:

- considerably higher strength, which allows thinner walls,
- very good resistance to pitting,
- higher resistance to stress corrosion cracking, especially in chloride-containing media,
- lower thermal expansion.

In the welded condition, duplex steels are generally used between −50 and +250 °C, super duplex steels up to +220 °C.

The grades

They are distinguished by the pitting resistance equivalent PRE, which describes the resistance to pitting: duplex below 40, super duplex from 40. Lean duplex grades contain little or no molybdenum.

PRE = % Cr + 3,3 · % Mo + 16 · % N

Steel name	Material no.	PRE (guide value)	Group
X2CrNiN23-4	1.4362	25	Lean duplex
X3CrNiMoN27-5-2	1.4460	30	Duplex
X2CrNiMoN22-5-3	1.4462	35	Duplex, the most widely used grade
X2CrNiMoN25-7-4	1.4410	42	Super duplex
X2CrNiMoCuWN25-7-4	1.4501	40	Super duplex
X2CrNiMoCuN25-6-3	1.4507	40	Super duplex

Grades according to EN 10088 with guide values of the pitting resistance equivalent according to DVS 0946. For tungsten-containing grades, the equivalent is sometimes calculated including tungsten. On the pitting resistance equivalent, see also What makes stainless steel stainless (page 88).

What happens in the microstructure during welding

Duplex steel first solidifies fully ferritic. Only on cooling does part of the ferrite transform into austenite. In welding there is little time for this, so the weld contains more ferrite than the base material.

- **Cooling time t12/8:** the decisive factor is the time between 1200 and 800 °C. It must be long enough for sufficient austenite to form.
- **Over-alloyed filler metals:** filler metals contain more nickel and nitrogen than the base material. Both promote austenite and compensate for the short cooling time.
- **Staying hot too long is also bad:** with prolonged dwell between about 300 and 1000 °C, sigma phase, chi phase, chromium nitrides and carbides form; around 475 °C there is a risk of embrittlement. This costs toughness and corrosion resistance.

The basics of the microstructure are covered in Microstructure, delta ferrite and hot cracking (page 89).

How much ferrite is acceptable?

DVS 0946 recommends 30 to at most 70 FN in the weld metal. Below that, resistance to stress corrosion cracking falls; above it, toughness, ductility and corrosion resistance suffer.

- Weld metal diluted with the base material generally has more ferrite. In TIG weld metal, up to 85 FN is generally still considered acceptable.
- For the austenite content, DVS 0946 likewise gives 30 to 70 % if no solution annealing is carried out.
- **Measuring:** magnetically according to ISO 8249. Evaluation on a metallographic section has proved unreliable in round-robin tests because the ferrite is very fine and unevenly distributed.
- **Estimating:** with the WRC-1992 diagram, which extends to 100 FN and takes nitrogen and copper into account. Schaeffler and DeLong do not reliably cover the duplex range: Schaeffler, DeLong and WRC calculator.

Also in the full article on migal.co: The right filler metal · Shielding gas and root protection · Heat control · Execution · Heat treatment

Dissimilar joints.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

WHAT IT IS ABOUT

When stainless steel is welded to carbon steel, both materials mix with the filler metal in the weld. The filler metal must be chosen so that this mixture becomes neither hard and crack-prone nor susceptible to hot cracking. Such joints are known as dissimilar joints (black-and-white joints).

The weld has to meet the requirements of both base materials. Depending on the composition of the weld metal, the risks are:

- **hardening cracks**, if there is too little chromium and nickel in the weld metal and martensite forms,
- **hot cracks**, if the weld metal solidifies without ferrite,
- **embrittlement by sigma phase**, if there is too much ferrite and chromium.

The basics of the microstructure are covered in Microstructure, delta ferrite and hot cracking (page 89).

Dilution is decisive

Without filler metal, the weld would consist of roughly half carbon steel and half stainless steel. In the Schaeffler diagram, this mixture lies in the martensite region and would harden. An over-alloyed filler metal pulls the weld metal back into the safe region.

This is how the check with the Schaeffler diagram works:

- Calculate the chromium and nickel equivalents of both base materials from their analysis, ideally from the inspection certificate 3.1, otherwise from the standard analysis.
- The midpoint between the two points is the base material mixture.
- Plot the point of the filler metal and connect it to the mixture.
- The weld metal lies on this line, closer to the filler metal or to the mixture depending on the dilution. The ISER information sheet uses 25 % base material in its example.

The Schaeffler calculator for dissimilar base materials does this, including dilution.

Example: S355 to 1.4301

With typical analyses, the mixture of S355 and 1.4301 has a chromium equivalent of about 9.6 and a nickel equivalent of about 8.1, which is in the martensite region. With filler metal, the result depends on the dilution:

Filler metal	20 % dilution	30 % dilution	40 % dilution
308LSi (19 9 L Si)	about 7 % ferrite	about 4 % ferrite	no ferrite left
309LSi (23 12 L Si)	about 7 % ferrite	about 5 % ferrite	just under 1 % ferrite
307 (18 8 Mn)	fully austenitic	fully austenitic	fully austenitic

Own calculation with the Schaeffler diagram and typical analyses; real values depend on the certificates.

- **309L** retains a few per cent of ferrite at normal dilution and is therefore safe against hot cracking. It tolerates the most dilution and is therefore the standard for dissimilar joints.
- **308L** works at low dilution, but loses its ferrite at high dilution and approaches the martensite region.
- **307** solidifies fully austenitic. The manganese stabilises the austenite and binds sulphur as manganese sulphide, which counteracts the risk of hot cracking.

In practice

The aim is dilution that is as uniform as possible and not too high.

- **Process:** Dissimilar joints are mainly welded with manual metal arc and gas-shielded processes, see Processes at a glance (page 91).
- **Limit dilution:** The penetration into the base materials determines the dilution. With more passes and less penetration, it stays lower.
- **Heat control** according to the more sensitive material: if the carbon steel needs preheating, this also applies here. Preheat temperatures are provided by the Preheat temperature calculator.
- **Keep tools separate:** Grinding dust from carbon steel must not get onto the stainless steel, otherwise extraneous rust forms, see Joint preparation and tack welding (page 94).

Also in the full article on migal.co: Choosing the filler metal · Galvanic corrosion at the joint

Full article on migal.co
migal.co/en/service/welding-of-stainless-steel/dissimilar-joints

Weld defects and corrosion damage.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

TWO KINDS OF DAMAGE

There are two groups of damage at stainless steel welds: defects that occur during welding, and corrosion that only shows up in service. Many cases of corrosion damage, however, already originate in fabrication.

Typical examples are temper colours that were not removed, iron abrasion from the wrong tools, or a crevice in a weld without full penetration. The tables give cause and remedy and refer to the articles in this series.

Defects during welding

The most common weld defects in stainless steels and what helps against them.

Defect	Cause	Remedy
Hot cracks (solidification cracks) in the weld centre	weld metal solidifies without ferrite, e.g. with fully austenitic grades; too much heat	filler metal with some ferrite, low heat input, stringer beads; Microstructure (page 89)
Crater cracks	the weld pool at the end of the weld solidifies last and cracks	fill craters; with fully austenitic grades, grind tack welds and weld ends
Cracks in dissimilar joints	too much dilution with carbon steel, martensite in the weld metal	over-alloyed filler metal such as 309L; Dissimilar joints (page 98)
Cracks at tack welds on duplex	rapid cooling, highly ferritic weld metal	tack with filler metal, preheat if necessary; Tack welding (page 94)
Lack of fusion	viscous weld pool, groove angle too narrow, weld pool running ahead of the arc	groove angle of 70 to 80° for duplex, adjust torch guidance; Joint preparation (page 94)
Porosity	disturbed gas shield, damp hoses, too much nitrogen, hydrogen in the arc	check gas shield, limit nitrogen; Shielding gases (page 92)
Root concavity, blown-out root	forming gas escapes only through the gap, overpressure too high	separate gas outlet, only slight overpressure; Root protection (page 95)
Excessive root penetration	too much heat or too wide a root gap	avoid because of the notch effect; grind out the root before a backing run
Arc strikes next to the weld	arc struck on the plate	strike only in the groove; arc strikes can initiate cracks and rust
Oxidised, “burnt” root	no or poor root protection	purge, measure residual oxygen; Root protection (page 95)
Heavy temper colours	too much heat, poor gas shield, moisture	Avoiding and removing temper colours (page 96)
Distortion	high thermal expansion, poor thermal conductivity	low heat input, close tack welds, fixtures; Heat control (page 93)

Based on DVS 0931, DVS 0937, DVS 0946 and ISER information sheet 823. Which imperfections are permissible and to what extent is governed by ISO 5817 with its quality levels.

Also in the full article on migal.co: Corrosion damage at welds · Rust at the weld: the usual suspects · Testing and assessment

Testing and quality assurance.

By Robert Lahnsteiner, welding engineer (SFI/IWE)

NON-DESTRUCTIVE TESTING

Not all test methods that are common for carbon steel work on austenitic stainless steel welds. Magnetic particle testing is ruled out, and ultrasonic testing is only of limited use. For surface cracks, penetrant testing is the method of choice.

Method	Used for	Limits on stainless steel	Standard
Visual testing (VT)	always, as the first test	weld shape, surface imperfections, temper colours	ISO 17637
Penetrant testing (PT)	surface cracks on all materials	only imperfections open to the surface	ISO 3452-1
Magnetic particle testing (MT)	only ferritic and martensitic grades	austenitic steels cannot be magnetised and therefore cannot be tested	ISO 17638
Eddy current testing (ET)	surface imperfections on conductive materials	requires suitable probes and experience	ISO 17643
Radiographic testing (RT)	pores, cavities, undercuts, lack of fusion in the beam direction	planar imperfections transverse to the beam hardly visible, no depth information from a single exposure	ISO 17636
Ultrasonic testing (UT)	internal imperfections, including their depth	considerably limited on stainless steel: the grain structure of the weld metal scatters the sound and simulates imperfections; only from 6 mm wall thickness	ISO 17640

Based on DVS 0931, section 10; standards brought up to date. The method and extent of testing depend on the loading of the component and the applicable code. NDT personnel must be qualified to ISO 9712.

Which imperfections are permissible is governed by the quality levels of ISO 5817. Causes of typical defects: Weld defects and corrosion damage (page 99).

What is additionally tested on stainless steel

Besides cracks and pores, the microstructure and surface determine the corrosion resistance of stainless steel. There are dedicated tests for these.

Feature	Wie	Standard	More on this
Ferrite content	magnetically with a ferrite meter, result in FN	ISO 8249	Microstructure (page 89), Duplex (page 97)
Residual oxygen during purging	residual oxygen meter close to the root	DVS 0937	Root protection (page 95)
Temper colours	comparison with colour charts or reference samples	by agreement	Temper colours (page 96)
Resistance to pitting corrosion	critical pitting temperature (CPT) in the ferric chloride test	ASTM G48	Duplex (page 97)
Resistance to intergranular corrosion	intergranular corrosion test	ISO 3651-2	Basics (page 88)
Interpass temperature	contact thermometer or temperature indicating crayon	ISO 13916	Heat control (page 93)

Which of these tests are required is specified by the order, the applicable code or the welding procedure specification.

Quality assurance

The quality requirements for fusion welding are set out in ISO 3834, the tasks of welding coordination in ISO 14731.

- **Welding procedure specification (WPS)** to ISO 15609-1, qualified by a procedure test to ISO 15614-1. The purging procedure belongs in it as well.
- **Welder qualification** to ISO 9606-1.
- **Approved wire-gas combination** for welds subject to acceptance; for construction products subject to building regulations, only approved filler metals and consumables.
- **Material certificates:** For the choice of filler metal and the Schaeffler diagram, inspection certificates 3.1 to EN 10204 are the best basis.

Also in the full article on migal.co: Health and safety during welding · Forming gas and pickling acid

Stainless

Full article on migal.co
migal.co/en/service/welding-of-stainless-steel/testing

Wire electrodes and welding rods

Nickel alloys.

5 nickel-based filler metals for corrosion-resistant, creep-resistant and cryogenic joints, for dissimilar joints and for welding cast iron.

NiCr20Nb	S Ni 6082	102
NiCr21Mo9Nb	S Ni 6625	103
NiCu30MnTi	S Ni 4060	104
NiFe2	SG - NiFe2	105
NiTi4	S Ni 2061	106

Nickel alloys › Data sheet

NiCr20Nb.

Wire electrodes/welding rods for nickel alloys

Typical composition of the filler metal in %

Ni	Cr	Fe	C	Mn	Si	Cu	Ti	Nb	S
≥ 67	18–22	≤ 3,0	≤ 0,05	2,5–3,5	≤ 0,5	≤ 0,5	≤ 0,75	≤ 3,0	≤ 0,015

Classification

EN ISO 18274	S Ni 6082 (NiCr20Mn3Nb)
DIN 1736	SG - NiCr20Nb
Material no.	2.4806
AWS A 5.14	ER NiCr-3
BS 2901	NA 35

Application

Solid nickel chrome wire electrode suitable for welding nickel alloys and joining austenitic to ferritic steels subjected to ambient temperatures exceeding 300°C and joining dissimilar materials. The weld metal is scale-resisting up to 1000° C and good toughness down to -196° C. Suitable for Austenite-Ferrite joints up to 550° C.

Dissimilar joints: Ni-Base with Austenite / Ni-Base with Ferrite / Austenite with Ferrite up to 550° C

Properties approx. values

Tensile strength R_m [MPa]	800
Specific electr. Resistance [Ω·mm²/m]	1,10
Density [g/cm³]	8,3
Melting temperature [°C]	1.400

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	MIG: Ar+1-3% O_2, Ar+1-3% CO_2, Ar+He+O_2, Ar+He+CO_2, Ar+He+CO_2+H_2 TIG: Ar, He, Ar+He, Ar+2-5% H_2
Polarity	MIG = +, TIG = –

Base materials

2.4630 NiCr20Ti	2.4631 NiCr21TiAl	2.4669 NiCr15Fe7TiAl	2.4816 NiCr15Fe	2.4817 LC-NiCr15Fe
2.4851 NiCr23Fe	2.4867 NiCr60 15	2.4869 NiCr80 20	2.4870 NiCr 10	2.4951 NiCr20Ti
1.5637 12 Ni 14	1.5662 X8Ni9	1.5680 12Ni19	1.6900 X12CrNI18 9	1.6901 GX8CrNi18 10
1.6903 X10CrNiTi18 10	1.6906 X5CrNi18 10			

Dimensions and packaging

MIG wire Ø [mm] 1,0 1,2 1,6

TIG rod Ø [mm] 1,6 2,0 2,4

Wire electrodes	Packaging unit
BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Nickel

Current data sheet and stock level
migal.co/en/products/nickel/nicr20nb

Nickel alloys › Data sheet

NiCr21Mo9Nb.

Wire electrodes/welding rods for nickel alloys

Typical composition of the filler metal in %

Ni	Cr	Fe	C	Mn	Si	Cu
≥ 60	20–23	≤ 5,0	≤ 0,10	0,5	≤ 0,5	≤ 0,5
Ti	**Al**	**Mo**	**Nb**	**S**	**P**	**Co**
≤ 0,4	≤ 0,4	8,0–10,0	3,15–4,15	≤ 0,015	≤ 0,02	≤ 1,0

Classification

EN ISO 18274	S Ni 6625 (NiCr22Mo9Nb)
DIN 1736	SG - NiCr21Mo9Nb
Material no.	2.4831
AWS A 5.14	ER NiCrMo-3

Application

Nickel base wire electrode for welding nickel alloys and could tough nickel steels, joining dissimilar steels and welding joints between austenitic and ferritic metals. Operating temperature -196° C bis +550° C.

Dissimilar joints: Ni-Base with Austenite / Ni-Base with Ferrite / Austenite with Ferrite up to 550° C

Properties approx. values

Tensile strength R_m [MPa]	800
Specific electr. Resistance [Ω·mm²/m]	1,28
Density [g/cm³]	8,4
Melting temperature [°C]	1.350
Thermal conductivity [W/m K]	9,8
Thermal expansion 20 - 100 °C [1/K]	$13 \cdot 10^{-6}$
Modulus of elasticity [N/mm²]	200.000

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	MIG: Ar+1-3% O_2, Ar+1-3% CO_2, Ar+He+O_2, Ar+He+CO_2, Ar+He+CO_2+H_2 TIG: Ar, He, Ar+He, Ar+2-5% H_2
Polarity	MIG = +, TIG = –
Approvals	TÜV

Base materials

1.4558 X2NiCrAlTi32-20	2.4631 NiCr20TiAl	2.4605 NiCr23Mo16Al	2.4618 NiCr22Mo6Cu	2.4619 NiCr22Mo7Cu
2.4630 NiCr20Ti	2.4641 NiCr21Mo6Cu	2.4660 NiCr20CuMo	2.4951 NiCr20Ti	2.4816 NiCr15Fe
2.4817 LC-NiCu15Fe	2.4851 NiCr23Fe	2.4856 NiCr22Mo9Nb	2.4858 NiCr21Mo	1.4951 X6CrNi25-20
1.5662 X8Ni9	1.5680 X12Ni5	1.5681 GX10Ni5	1.6907 X3CrNiN18-10	1.6967 X3CrNiMoN18-4
1.4876 X10NiCrAlTi32-20	1.4959 X8NiCrAlTi32-21	Alloy 800, 800HT		

Dimensions and packaging

MIG wire Ø [mm] 1,0 1,2 1,6

TIG rod Ø [mm] 1,6 2,0 2,4

Wire electrodes	Packaging unit
BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Current data sheet and stock level
migal.co/en/products/nickel/nicr21mo9nb

Nickel alloys › Data sheet

NiCu30MnTi.

Wire electrodes/welding rods for nickel alloys

Typical composition of the filler metal in %

Ni	Fe	C	Mn	Si	Cu	Ti	Al	Nb	S	P
≥ 62	0,5–2,5	≤ 0,15	2,0–4,0	≤ 1,0	28–34	1,5–3,5	≤ 1,0	≤ 0,5	≤ 0,015	≤ 0,02

Classification

EN ISO 18274	S Ni 4060 (NiCu30Mn3Ti)
DIN 1736	SG - NiCu30MnTi
Material no.	2.4377
AWS A 5.14	ER NiCu-7
BS 2901	NA 33

Application

Solid Nickel copper welding wire electrode suitable for joinig nickel copper alloys and copper to steel, claddings and buffer layers.

Properties approx. values

Tensile strength R_m [MPa]	550
Yield strength $R_{p0,2}$ [MPa]	250
Elongation A200 [%]	35
Hardness [HV]	135
Specific electr. Resistance [Ω·mm²/m]	0,62
Density [g/cm³]	8,5
Melting temperature [°C]	1.330

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	MIG: Ar+1-3% O_2, Ar+1-3% CO_2, Ar+He+O_2, Ar+He+CO_2, Ar+He+CO_2+H_2 TIG: Ar, He, Ar+He, Ar+2-5% H_2
Polarity	MIG = +, TIG = –

Base materials

2.4360 NiCu 30 Fe | 2.4361 LC-NiCu 30 Fe | 2.4365 G-NiCu Nb | 2.4375 NiCu 30 Al

Dimensions and packaging

MIG wire Ø [mm]: 1,0 | 1,2 | 1,6

TIG rod Ø [mm]: 1,6 | 2,0 | 2,4

Wire electrodes	Packaging unit
BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Nickel

Current data sheet and stock level
migal.co/en/products/nickel/nicu30mnti

Nickel alloys › Data sheet

NiFe2.

Stainless steel wire electrodes/welding rods

Typical composition of the filler metal in %

Ni	Fe	C	Mn	Si	Cu	Ti	Al	S	P
≥ 53	Balance	≤ 0,20	1,0–4,0	≤ 0,3	≤ 2,5	0,2–0,5	≤ 0,2	≤ 0,02	≤ 0,02

Classification

DIN 8573	SG - NiFe2
AWS A 5.14	ER NiFe-Cl

Application

This alloy is particularly suited for welding of ferritic and austenitic nodular Cast iron as well as for joining it with non-alloy and high-alloy steel, copper and nicke1 alloys. Buildups on grey Cast iron qualities are also possible. Special applications are construction welding of ductile centrifugal casting tubes, such as joggles and flange joints, fittings, Pumps, and for corrosion resistant claddings. The deposit is tough, crack resistant and easily machinable with cutting tools.

Properties approx. values

Tensile strength R_m [MPa]	800
Specific electr. Resistance [Ω·mm²/m]	0,4
Density [g/cm³]	8,4
Melting temperature [°C]	1.440

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	MIG: Ar+1-3% O_2, Ar+1-3% CO_2, Ar+He+O_2, Ar+He+CO_2, Ar+He+CO_2+H_2 TIG: Ar, He, Ar+He, Ar+2-5% H_2
Polarity	MIG = +, TIG = –

Dimensions and packaging

MIG wire Ø [mm]	1,0 1,2 1,6
TIG rod Ø [mm]	1,6 2,0 2,4

Wire electrodes	Packaging unit
BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Nickel

Nickel alloys › Data sheet

NiTi4.

Wire electrodes/welding rods for nickel alloys

Typical composition of the filler metal in %

Ni	Fe	C	Mn	Si	Cu	Ti	Al	S
≥ 93	≤ 0,7	≤ 0,05	0,8	≤ 0,8	≤ 0,2	≤ 4,0	≤ 1,0	≤ 0,01

Classification

EN ISO 18274	S Ni 2061 (NiTi3)
DIN 1736	SG - NiTi4
Material no.	2.4155
AWS A 5.14	ER Ni-1
BS 2901	NA 32

Application

Massive wire electrode suitable for welding pure nickel and nickel alloys as well as joints between these materials and steel, cast steel, copper claddings and buffer layers.

Properties approx. values

Tensile strength R_m [MPa]	550
Yield strength $R_{p0,2}$ [MPa]	250
Elongation A200 [%]	35
Hardness [HV]	135
Specific electr. Resistance [Ω·mm²/m]	0,29
Density [g/cm³]	8,7
Melting temperature [°C]	1.430

Processing

Welding position	PA PB PC PD PE PF
Shielding gas	MIG: Ar+1-3% O_2, Ar+1-3% CO_2, Ar+He+O_2, Ar+He+CO_2, Ar+He+CO_2+H_2 TIG: Ar, He, Ar+He, Ar+2-5% H_2
Polarity	MIG = +, TIG = –

Base materials

2.4056 | 2.4062 | 2.4066 | Nickel 200 | Nickel 201 | Nickel 99

Dimensions and packaging

MIG wire Ø [mm]: 1,0 | 1,2 | 1,6

TIG rod Ø [mm]: 1,6 | 2,0 | 2,4

Wire electrodes	Packaging unit
BS 300 / 15 kg	25 spools = 375 kg (Pallet)

Current data sheet and stock level
migal.co/en/products/nickel/niti4

Wire electrodes and welding rods

Low-alloy steels.

6 filler metals for unalloyed and low-alloy steels: TIG rods for structural steels, filler metals for creep-resistant Mo and CrMo steels and a wire electrode for high-strength fine-grained structural steels with yield strengths up to 690 MPa.

ML-WSG2	3Si1	1.5125	108
ML-WSG3	4Si1	1.5130	109
ML-Mo	2Mo	1.5424	110
ML-CrMo1	CrMo1Si	1.7339	111
ML-CrMo2	CrMo2Si	1.7384	112
ML-FK1	69 4 Mn3Ni1CrMo		113

Low-alloy steels › Data sheet

ML-WSG2 1.5125 · 3Si1.

Low-alloy welding rods

Typical composition of the filler metal in %

C	Si	Mn
0,09	0,87	1,47

Classification

DIN EN ISO 636-A	W 46 5 3Si1
AWS	A5.18 ER70S-6
Material no.	1.5125

Base materials

For steels up to a yield strength of 420MPa (60ksi). S185-E360, S235JR-S355JR, S235J0-S355J0, S235J2-S355J2, S275N-S420N, S275NL-S420NL, S275M-S420M, S275ML-S420ML, P275N-P355N, P275NL1-P355NL1, P275NL2-P355NL2, P355M-P420M, P355ML2-P420ML2, P355Q, P355QL1 ASTM: A36, A106 grades A/B/C, A139, A210 grades A1/C, A214, A216 grades WCA/WCB/WCC, A234 grade WPB, A334 grade 1 API: 5L grades X42-X60

Properties approx. values

Yield strength in MPa	≥ 460
Tensile strength in MPa	≥ 560
Elongation in %	4d/5d: ≥22/20
Charpy-V-Value (ISO-V) in J	RT ≥ 100, -50 °C ≥ 47

Processing

Polarity	TIG = –
Approvals	TÜV, DB, CE

Characteristics and application

TIG/GTAW rod for welding standard CMn structural steels. Typical applications would include shipbuilding, pressure vessels and construction.

Typical heat treatment

Preheat and PWHT are generally not necessary but actual requirements will depend on the grade and thickness of material being welded and any design codes that apply.

Dimensions and packaging

TIG rod Ø [mm]	2,0	2,4

Low alloy

Current data sheet and stock level
migal.co/en/products/low-alloyed-welding-wires/15125-3si1-ml-wsg2

ML-WSG3 1.5130 · 4Si1.

Low-alloy welding rods

Typical composition of the filler metal in %

C	Si	Mn
0,09	0,95	1,67

Classification

DIN EN ISO 636-A	W 50 5 4Si1
AWS	A5.18 ER70S-6
Material no.	1.5130

Base materials

For steels up to a yield strength of 460MPa (65ksi). S185-E360, S235JR-S355JR, S235J0-S450J0, S235J2-S355J2, S275N-S460N, S275M-S460M, S460Q, S460QL, P275N-P460N, P275NL1-P460NL1, P355M-P460M, P355ML1-P460ML1, P355Q-P460Q, P355QL1-P460QL1 ASTM: A36, A106 grades A/B/C, A139, A210 grades A1/C, A214, A216 grades WCA/WCB/WCC, A234 grade WPB, A334 grade 1 API: 5L grades X42-X60

Properties approx. values

Yield strength in MPa	≥ 500
Tensile strength in MPa	≥ 560
Elongation in %	4d/5d: ≥18
Charpy-V-Value (ISO-V) in J	RT ≥ 100, -50 °C ≥ 80

Processing

Polarity	TIG = –
Approvals	CE

Characteristics and application

TIG/GTAW rod for welding standard CMn structural steels. Typical applications would include shipbuilding, pressure vessels and construction.

Typical heat treatment

Preheat and PWHT are generally not necessary but actual requirements will depend on the grade and thickness of material being welded and any design codes that apply.

Dimensions and packaging

TIG rod Ø [mm]	1,0	1,2	1,6	2,0	2,4	3,0

Low-alloy steels › Data sheet

ML-Mo 1.5424 · 2Mo.

Low-alloy wire electrodes/welding rods

Typical composition of the filler metal in %

C	Si	Mn	Mo
0,10	0,60	1,15	0,52

Classification

DIN EN ISO 14341-A MAG	G 42 2 C1 2Mo, G 46 6 M21 2Mo
DIN EN ISO 21952-A MAG	G MoSi
DIN EN ISO 636-A TIG	W 46 4 2Mo
DIN EN ISO 21952-A	W MoSi
Material no.	1.5424
AWS	A5.28 ER70S-A1, A5.28 ER80S-G

Base materials

For similar alloyed high temperature steels and cast steels, ageing resistant and steels resistant to caustic cracking. P235G1TH-P255G1TH, P310GH, L320, L360NB-L415NB, 16Mo3 ASTM: A182/A336 F1, A204 grades A/B/C, A209/A250 T1, A217 WC1, A335 P1, A352 LC1

Properties approx. values

Yield strength in MPa	≥ 460
Tensile strength in MPa	≥ 560
Elongation in %	4d/5d: ≥22
Charpy-V-Value (ISO-V) in J	RT ≥ 60, -40 °C ≥ 47

Processing

Polarity	MAG = +, TIG = –
Approvals	TÜV, DB, CE

Characteristics and application

Wire/rod for 0.5%Mo steels. These steels are commonly used at service temperatures up to 500°C and for some sub-zero structural applications. The 0.5% alloying improves creep performance compared to CMn steels and sees the alloy being used for boiler, pressure vessel and piping construction. The good general mechanical properties also ensures use in general structural engineering applications.

Typical heat treatment

Preheat temperature: Dependent on material thickness
Interpass temperature: max. 250°C PWHT: AW or 650°C

Dimensions and packaging

MIG wire Ø [mm] 0,8 | 1,0 | 1,2

TIG rod Ø [mm] 2,0 | 2,4 | 3,0

Wire electrodes	Packaging unit	Packaging unit
B 300 / 18 kg	56 spools = 1.008 kg (Pallet approximately 120x80x100 cm)	2 drums = 500 kg (Pallet approximately 120x80x105 cm)
	BOX 1-drum / 250 kg	

Low alloy

Current data sheet and stock level
migal.co/en/products/low-alloyed-welding-wires/15424-2mo-ml-mo

ML-CrMo1 1.7339 · CrMo1Si.

Low-alloy wire electrodes/welding rods

Typical composition of the filler metal in %

C	Si	Mn	Cr	Mo
0,10	0,60	1,00	1,20	0,52

Classification

DIN EN ISO 21952-A MAG	G CrMo1Si
DIN EN ISO 21952-A TIG	W CrMo1Si
Material no.	1.7339
AWS	A5.28 ER80S-G

Properties approx. values

Yield strength in MPa	≥ 355
Tensile strength in MPa	≥ 510
Elongation in %	4d/5d: ≥20
Charpy-V-Value (ISO-V) in J	RT ≥ 100, -40 °C ≥ 47

Base materials

For matching 1.25%Cr-0.5%Mo creep resisting ferritic steels. 13CrMo 4-4, 13CrMo 4-5, 16CrMo 4-4, G-17CrMo 5-5 ASTM: A182 grades F11/F12, A199/A200 grade T11, A217 grades WC6/WC11, A234 grades WP11/WP12, A335 grades P11/P12, A387 grades 11/12

Processing

Polarity	MAG = +, TIG = –
Approvals	TÜV, DB, CE

Characteristics and application

Wire/rod for high temperature creep resistant 1.25%Cr-0.5%Mo ferritic steels, i.e. P11/P12. These steels are used for creep resisting applications up to ~550°C. Typical applications in power generation plant include steam piping, turbines and boilers; the alloy also finds applications in the chemical and petro-chemical industries. The wire has low levels of tramp elements (eg. Sn, As, Sb and P) providing a low Bruscato Factor (X< 10 ppm) for temper embrittlement resistant applications.

Typical heat treatment

Preheat temperature: Dependent on material thickness
Interpass temperature: max. 250°C PWHT: AW or 650°C

Dimensions and packaging

MIG wire Ø [mm]	0,8	1,0	1,2

TIG rod Ø [mm]	2,0	2,4

Wire electrodes	Packaging unit	Packaging unit
B 300 / 18 kg	56 spools = 1.008 kg (Pallet approximately 120x80x100 cm)	2 drums = 500 kg (Pallet approximately 120x80x105 cm)
	1 drum / 250 kg	

Low-alloy steels › Data sheet

ML-CrMo2 1.7384 · CrMo2Si.

Low-alloy wire electrodes/welding rods

Typical composition of the filler metal in %

C	Si	Mn	Cr	Mo
0,08	0,60	0,92	2,45	1,00

Classification

DIN EN ISO 21952-A MAG	G CrMo2Si
DIN EN ISO 21952-A TIG	W CrMo2Si
Material no.	1.7384
AWS	A5.28 ER90S-G

Properties approx. values

Yield strength in MPa	≥ 400
Tensile strength in MPa	≥ 520
Elongation in %	4d/5d: ≥20
Charpy-V-Value (ISO-V) in J	RT ≥ 80

Base materials

For matching 2.5%Cr-1%Mo creep resisting ferritic steels. 10CrMo 9-10, G-17CrMo 9-10 ASTM: A182 grade F22, A199/A200 grades T21/T22, A213 grade T22, A217 grade WC9, A234 grade WP22, A335 grade P22, A387 grades 21/22

Processing

Polarity	MAG = +, TIG = –
Approvals	TÜV, DB, CE

Characteristics and application

Wire/rod for high temperature creep resistant 2.25%Cr-1%Mo ferritic steels, i.e. P21/P22. These steels are used for creep resisting applications up to ~600°C. Typical applications in power generation plant include steam piping, turbines and boilers; the alloy also finds applications in the chemical and petro-chemical industries. The wire has low levels of tramp elements (eg. Sn, As, Sb and P) providing a low Bruscato Factor (X< 10 ppm) for temper embrittlement resistant applications.

Typical heat treatment

Preheat temperature: 200°C Interpass temperature: max. 300°C PWHT: 690°C

Dimensions and packaging

MIG wire Ø [mm]	0,8	1,0	1,2

TIG rod Ø [mm]	2,0	2,4

Wire electrodes	Packaging unit	Packaging unit
B 300 / 18 kg	56 spools = 1.008 kg (Pallet approximately 120x80x100 cm)	2 drums = 500 kg (Pallet approximately 120x80x105 cm)

Low alloy

Current data sheet and stock level
migal.co/en/products/low-alloyed-welding-wires/17384-crmo2si-ml-crmo2

ML-FK1 69 4 Mn3Ni1CrMo.

Low-alloy wire electrodes

Typical composition of the filler metal in %

C	Si	Mn	Cr	Ni	Mo	V
0,09	0,52	1,57	0,30	1,40	0,25	0,09

Classification

DIN EN ISO 16834-A MAG	G 69 4 M21 Mn3Ni1CrMo
AWS	A5.28 ER100S-G, A5.28 ER110S-G

Base materials

For high strength fine-grained steels with yield strength up to 690MPa (100ksi). S500Q-S690Q, S500QL-S690QL, P500Q-P690Q, P500QL1-P690QL1 Alform plate 700 M, NAXTRA 700, Strenx 700, Dillimax 690 ASTM: A514. HY80, HY100, Q1(N)

Characteristics and application

Wire for welding high strength low alloy steels. Used for many structural and construction applications including: mobile cranes, cement pumps, pipelines, tankers and containers.

Properties approx. values

Yield strength in MPa	≥ 690
Tensile strength in MPa	≥ 790
Elongation in %	4d/5d: ≥17
Charpy-V-Value (ISO-V) in J	-40 °C ≥47

Processing

Polarity	MAG = +
Approvals	MIG: TÜV, DB, CE

Typical heat treatment

Welding procedure, including preheat temperature, inter-pass temperature and PWHT, will be dependent on the base material being welded and any applicable design codes.

Dimensions and packaging

MIG wire Ø [mm]: 0,8 | 1,0 | 1,2

Wire electrodes	Packaging unit	Packaging unit	Packaging unit
B 300 / 18 kg	56 spools = 1.008 kg (Pallet approximately 120x80x100 cm)	BOX1-drum / 250 kg	2 drums = 500 kg (Pallet approximately 120x80x105 cm)

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migal.co/en

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