

VDM® Alloy 59
Nicrofer 5923 hMo

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VDM® Alloy 59 is a nickel-chrome-molybdenum alloy developed by VDM Metals, which has particularly low concentrations of carbon and silica and it is characterized by excellent corrosion resistance as well as high strength.

VDM® Alloy 59 is characterized by:

- excellent resistance against a multitude of corrosive media under oxidizing and reducing conditions,
- outstanding resistance against chloride-induced pitting and crevice corrosion, as well as resistance against stress corrosion cracking,
- excellent resistance in mineral acids such as nitric, phosphoric, sulfuric and salt acids, but especially against sulfur/salt acid mixtures,
- excellent resistance in contaminated mineral acids,
- very good processing characteristics and weldability with low propensity to form hot cracks,
- very resistant to sensitivation.

The material is on the list of materials acceptable for the transport of hazardous goods published by the BAM [German Federal Institute for Materials Research and Testing].

Designations

| Standard | Material Designation |
|----------|-----------------------|
| EN | 2.4605 – NiCr23Mo16Al |
| ISO | 15156/MR 0175 |
| UNS | N06059 |

Standards

| Product form | DIN | VdTÜV | ASTM | ASME | NACE | others |
|--------------|----------------|-------|----------------|------------------|-------------------|---------|
| Sheet | 17750 17744 | 505 | B 575 | SB 575 | MR 0175/ISO 15156 | |
| Strip | 17744 | 505 | B 575 | SB 575 | MR 0175/ISO 15156 | API 5LD |
| Bar | 17752 17744 | 505 | B 574 B 564 | SB 574 SB 564 | MR 0175/ISO 15156 | |
| Wire | 17744 | | | | | |

Table 1 – Designations and standards

Chemical composition

| | Fe | Cr | Ni | Mo | C | S | Mn | Si | Cu | P | Al | Co |
|------|-----|------|------|------|------|------|-----|-----|-----|-------|-----|-----|
| Min. | | 22,0 | | 15,0 | | | | | | | 0,1 | |
| Max. | 1,5 | 24,0 | Bal. | 16,5 | 0,01 | 0,01 | 0,5 | 0,1 | 0,5 | 0,015 | 0,4 | 0,3 |

Due to technical reasons the alloy may contain other elements than listed

Table 3 – Chemical composition (%) according to VdTÜV data sheet 505

Physical properties

| Density | Melting range | Relative magnetic permeability at 20 °C (68 °F) |
|---|--------------------------------------|---|
| 8,6 g/m ³ bei 20 °C 537 lb/ft ³ at 68 °F | 1.310 bis 1.360 °C (710 – 738 °F) | 1.001 |

| Temperature | | Specific heat capacity | | Thermal conductivity | | Electrical resistivity | Modulus of elasticity | | Coefficient of thermal expansion | |
|-------------|-------|------------------------|---------------------------------|-----------------------|--|------------------------|-----------------------|---------------------|----------------------------------|----------------------------|
| °C | °F | $\frac{J}{Kg \cdot K}$ | $\frac{Btu}{lb \cdot ^\circ F}$ | $\frac{W}{m \cdot K}$ | $\frac{Btu \cdot in}{sq. ft \cdot h \cdot ^\circ F}$ | $\mu\Omega \cdot cm$ | GPa | 10 ⁶ psi | $\frac{10^{-6}}{K}$ | $\frac{10^{-6}}{^\circ F}$ |
| 20 | 68 | 414 | 0.0989 | 10,4 | 6.01 | 126 | 210 | 30.5 | - | - |
| 100 | 212 | 425 | 0.102 | 12,1 | 6.99 | 127 | 207 | 30.0 | 11,9 | 6.61 |
| 200 | 392 | 434 | 0.104 | 13,7 | 7.92 | 129 | 200 | 29.0 | 12,2 | 6.78 |
| 300 | 572 | 443 | 0.106 | 15,4 | 8.90 | 131 | 196 | 28.4 | 12,5 | 6.94 |
| 400 | 752 | 451 | 0.108 | 17,0 | 9.82 | 133 | 190 | 27.6 | 12,7 | 7.06 |
| 500 | 932 | 459 | 0.11 | 18,6 | 10.7 | 134 | 185 | 26.8 | 12,9 | 7.17 |
| 600 | 1,112 | 464 | 0.111 | 20,4 | 11.8 | 133 | 178 | 25.8 | 13,1 | 7.28 |

Table 3 – Typical physical properties of VDM® Alloy 59 at elevated temperatures

Microstructural properties

VDM® Alloy 59 has a cubic, face-centered crystal structure.

Mechanical properties

The following properties apply to VDM® Alloy 59 in the solution-annealed condition and with the specified dimensions. The properties for larger dimensions must be agreed separately.

| Temperature | | Yield strength $R_{p0.2}$ | | Yield strength $R_{p1.0}$ | | Tensile strength R_m | | Elongation A |
|-------------|-----|------------------------------|------|------------------------------|------|---------------------------|---------|-----------------|
| °C | °F | MPa | ksi | MPa | ksi | MPa | ksi | % |
| 20 | 68 | 340 | 49.3 | 380 | 55.1 | 690-900 | 100-131 | 40 |
| 100 | 212 | 290 | 42.1 | 330 | 47.9 | 650 | 94.3 | 40 |
| 200 | 392 | 250 | 36.3 | 290 | 42.1 | 615 | 89.2 | 40 |
| 300 | 572 | 220 | 31.9 | 260 | 37.7 | 580 | 84.1 | 40 |
| 400 | 752 | 190 | 27.6 | 230 | 33.4 | 545 | 79.0 | 40 |
| 450 | 842 | 175 | 25.4 | 215 | 31.2 | 525 | 76.1 | 40 |

Table 4 – Mechanical short-term properties at room temperature and elevated temperatures (min. values according VdTÜV material data sheet 505)

| Product-form | Dimensions | | Yield stress $R_{p0.2}$ | | Yield stress $R_{p1.0}$ | | Tensile strength R_m | | Elongation at fracture A |
|--------------|-------------|--------------|----------------------------|------|----------------------------|------|---------------------------|------|-----------------------------|
| | mm | in | MPa | ksi | MPa | ksi | MPa | ksi | % |
| Sheet/ Plate | 0,5 – 6,4 | 0.0197-0.252 | ≥ 340 | 49.3 | ≥ 380 | 55.1 | ≥ 690 | 100 | ≥ 40 |
| Sheet/ Plate | 5 - 30 | 0.0197-118 | ≥ 340 | 49.3 | ≥ 380 | 55.1 | ≥ 690 | 100 | ≥ 40 |
| Strip | 0,5 bis 6,4 | 0.0197-0.252 | ≥ 340 | 49.3 | ≥ 380 | 55.1 | ≥ 690 | 100 | ≥ 40 |
| Bar | ≤100 | ≤ 3.94 | ≥ 340 | 49.3 | ≥ 380 | 55.1 | ≥ 690 | 100 | ≥ 40 |
| Bar | ≤100 | ≤ 3.94 | ≥ 320 | 46.4 | ≥ 360 | 52.1 | ≥ 650 | 94.3 | ≥ 40 |

Table 5 – Mechanical properties at room temperature (min. values according VdTÜV material datasheet 505)

ISO V impact value¹⁾

| | | |
|--|-------------------------------------|---|
| ISO –V impact strength ak (mean value) | 225 J/ cm ² (minimum) | ≥ 200J/cm ² at -196 °C (-122 °F) |
| ISO – V notch impact enegery ¹⁾ Kv | 180 J (133 ft/lbf) (minimum) | ≥160J at -196 °C (-122 °F) |

2) Source: VdTÜV- material datasheet 505

¹⁾ Cut axis perpendicular to the surface, sheet thickness ≤ 60 mm

Average value of 3 samples. Only one value can fall below the minimum average value at most by 30%.

The requirements refer to normal samples according to DIN EN ISO 148-1. For undersized samples, the values must be agreed separately with the manufacturer.

The values also apply for the heat-affected zone in welded joints.

Corrosion resistance

Due to the extremely low carbon and silica concentrations, VDM® Alloy 59 has no propensity for grain boundary dispersions in hot forming or welding. The alloy can therefore be used in many chemical processes with oxidizing and reducing media. Furthermore, VDM® Alloy 59 is more resilient against chloride ion attack due to its high nickel, chrome and molybdenum concentrations.

The corrosion tests described in the relevant standards usually refer to oxidizing conditions under which the VDM® Alloy 59 has proven to be clearly superior over all other Ni-Cr-Mo alloys. But VDM® Alloy 59 is also highly resistant under reducing conditions. Accordingly, its corrosion rate in boiling 10%-sulfuric acid is less than one-third of the attack measured on other introduced Ni-Cr-Mo alloys. With this excellent behavior, the alloy has also become successfully established in the chemical process industry in applications with reducing media.

Figures 1 and 2 show the excellent corrosion resistance of VDM® Alloy 59 in hydrochloric acid and sulfuric acid. Optimal corrosion resistance, however, can only be assured if the material is used in clean, metallic bright condition.

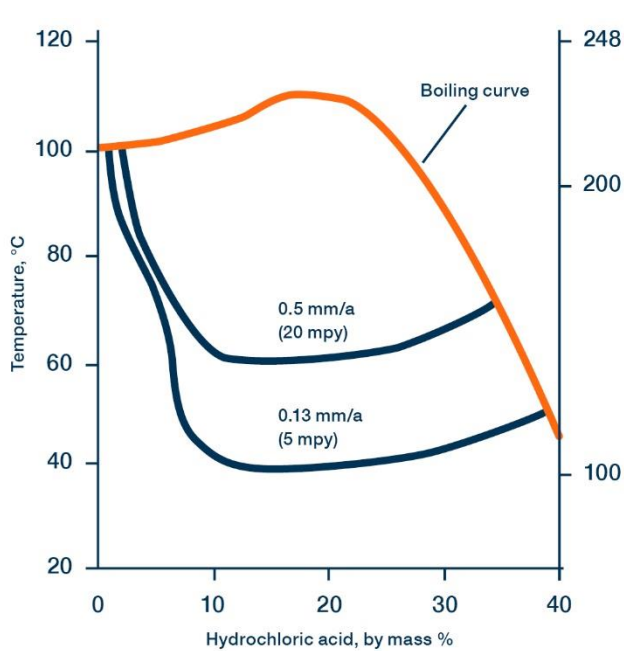


Fig. 1: ISO corrosion diagram of VDM® Alloy 59 in hydrochloric acid, as determined by static immersion tests

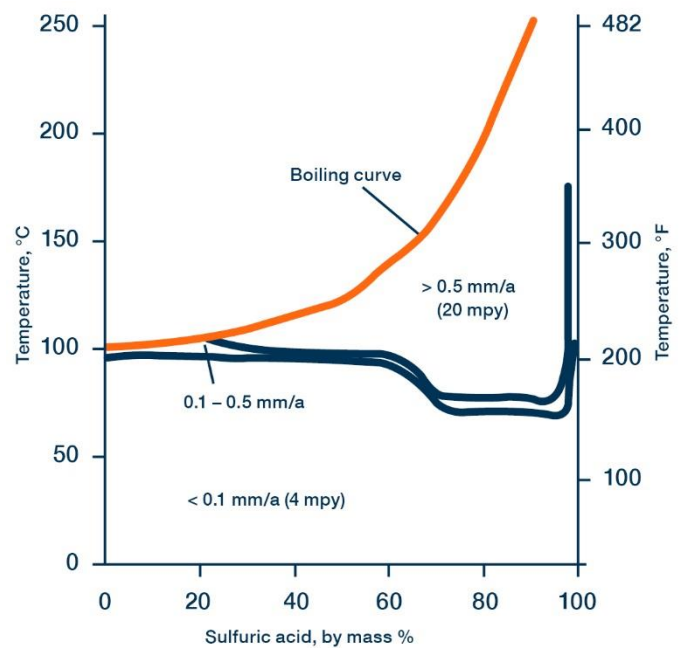


Fig. 2: ISO corrosion diagram of VDM® Alloy 59 in sulfuric acid, as calculated based on static immersion tests over at least 120h

Applications

VDM® Alloy 59 is suitable for a wide spectrum of applications in chemistry, petro chemistry, energy and environmental engineering. Typical applications are:

- Plant components for organic chemistry processes with media containing chloride, especially where catalytic systems on chloride basis are used.
- Multi-purpose plants in the chemicals industry
- Plant parts in active substance preparation and the pharmaceuticals industry
- Scrubber, heat exchangers, flaps, ventilators and agitators for flue gas desulfurization (FGD) in fossil fuel power plants and waste combustion plants
- SO₂-washers for ship diesel engines
- Components for seawater and concentrated brines
- Equipment and components for geothermal energy and acid gas applications
- Reactors for acetic acids and acetic anhydrides
- Reactors for hydrofluoric acid
- Sulfuric acid coolers

Fabrication and heat treatment

VDM® Alloy 59 is ideally suited for processing by means of common industrial processing techniques.

Heating

It is important that the workpieces are clean and free of any contaminants before and during heat treatment. Sulfur, phosphorus, lead and other low-melting point metals can result in material damage during the heat treatment. This type of contamination is also contained in marking and temperature-indicating paints or pens, and also in lubricating grease, oils, fuels and similar materials. The sulfur content of fuels must be as low as possible. Natural gas should contain less than wt.-0.1% sulfur. Heating oil with a maximum sulfur content of wt.-0.5% is also suitable. Electric furnaces are to be preferred due to precise temperature control and lack of contaminants due to fuel. The furnace temperature should be set between neutral and slightly oxidizing and should not change between oxidizing and reducing. The workpieces must not come in direct contact with flames.

Hot forming

VDM® Alloy 59 should be hot-worked in a temperature range between 1,180 and 950 °C (2,156-1,742 °F) with subsequent rapid cooling down in water or air. For heating up, workpieces should be placed in a furnace which has been heated up to the maximum hot forming temperature. Heat treatment after hot forming is recommended for achieving optimal corrosion behavior.

Cold forming

The workpieces should be in the annealed condition for cold forming. VDM® Alloy 59 has a significantly better work hardening rate than the widely used austenitic stainless steels. This must be taken into account during the design and selection of forming tools and equipment and during the planning of forming processes. Intermediate annealing is necessary for major cold forming work. For cold forming of > 15%, a final solution annealing must be conducted.

Heat treatment

The solution annealing should take place at temperatures between 1,100 and 1,180 °C (2,012-2,156 °F), preferably at 1,120°C (2,049 °F). The retention time during annealing depends on the semi-finished product thickness and it is calculated as follows:

- For thicknesses $d \leq 10$ mm, the retention time is $t = d \cdot 3$ min/mm
- For thicknesses $d = 10$ to 20 mm, the retention time $t = 30$ min + $(d - 10$ mm) · 2 min/mm
- For thicknesses $d > 20$ mm, the retention time $t = 50$ min + $(d - 20$ mm) · 1 min/mm

The retention time commences with material temperature equalization; longer times are generally considerably less critical than retention times that are too short.

Cooling down should be accelerated with water or air in order to achieve optimum properties. The material must be placed in a furnace that has been heated up to the maximum annealing temperature before any heat treatment. For the product forming belt, the heat treatment can be performed in a continuous furnace at a speed that is adapted to the strip thickness and a temperature that differs from the specified temperatures and times. The cleanliness requirements listed under "Heating" must be observed.

Descaling and pickling

Oxides of VDM® Alloy 59 and heat tint in the area around welds adhere more strongly than in stainless steels. Grinding using extremely fine abrasive belts or grinding discs is recommended. It is imperative that grinding burns be avoided. Before pickling in saltpeter-hydrofluoric acid mixtures, the oxide layers should be destroyed by abrasive blasting or fine grinding, or pre-treated in salt baths. The pickling baths used should be carefully monitored with regard to concentration and temperature.

Machining

Machining of VDM® Alloy 59 should take place in an annealed condition. Because of the considerably elevated tendency toward work hardening in comparison with low-alloy austenitic stainless steels, a low cutting speed and a feed level that is not too high should be selected and the cutting tool should be engaged at all times. An adequate chip depth is important in order to cut below the previously formed strain-hardened zone. Optimum heat dissipation through the use of large quantities of suitable, preferably aqueous, lubricants has considerable influence on a stable machining process.

Welding information

When welding nickel alloys and special stainless steels, the following information should be taken into account:

Safety

The generally applicable safety recommendations, especially for avoiding dust and smoke exposure must be observed.

Workplace

A separately located workplace, which is specifically separated from areas in which C steel is being processed, must be provided. Maximum cleanliness is required, and drafts should be avoided during gas-shielded welding.

Auxiliary equipment and clothing

Clean fine leather gloves and clean working clothes must be used.

Tools and machines

Tools that have been used for other materials may not be used for nickel alloys and stainless steels. Only stainless steel brushes may be used. Machines such as shears, punches or rollers must be fitted (e.g. with felt, cardboard, films) so that the workpiece surfaces cannot be damaged by such equipment due to pressed-in iron particles as this can lead to corrosion.

Edge preparation

Edge preparation should preferably be carried out using mechanical methods such as lathing, milling or planing. Abrasive waterjet cutting or plasma cutting is also possible. In the latter case, however, the cut edge (seam flank) must be cleanly reworked. Careful grinding without overheating is also permissible.

Striking

Striking may only take place in the seam area, such as on the seam flanks or on an outlet piece, and not on the component surface. Scaling areas are places that may be more susceptible to corrosion.

Included angle

Compared to C-steels, nickel alloys and special stainless steels exhibit lower thermal conductivity and greater heat expansion. Larger root gaps and root openings (1 to 3 mm) are required to live up to these properties. Due to the viscosity of the welding material (compared to standard austenitic steels) and the tendency to shrink, included angles of 60 to 70° – as shown in figure 3 – have to be provided for butt welds.

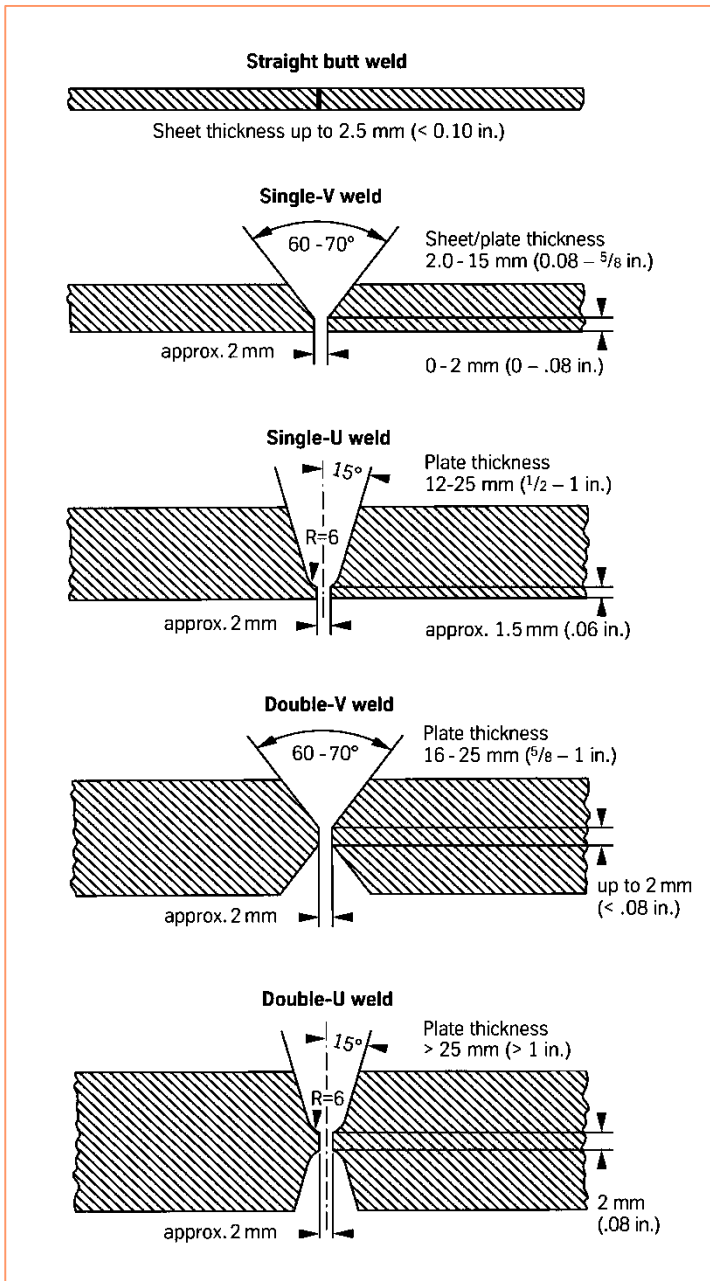


Figure 3 – Seam preparation for welding nickel alloys and special stainless steels

Cleaning

Cleaning of the base material in the seam area (both sides) and the welding filler (e.g. welding rod) should be carried out using acetone.

Welding technique

VDM® Alloy 59 can be welded using conventional processes with metals of the same type as well as many other metals. This includes TIG, GMAW (MIG/MAG), plasma, electron beam welding and handheld electrical welding. The use of a pulse technique is preferable during shielding gas welding processes. The use of a multi-component shielding gas (Ar + He + H₂ + CO₂) with low CO₂ concentrations (< 0.12%) is recommended for the MAG process. For welding, VDM® Alloy 59 should be in a solution-annealed condition and free of scale, grease and markings. When welding the root, care should be taken to achieve best quality root protection using pure argon (argon 4.6) so that the welding edge is free of oxides after welding the root. Root protection is also recommended for the first and, in certain cases depending on the welded construction, also for the second intermediate layer weld after root welding. Any heat tint in the intermediate layers must be removed while the welding edge is still hot, preferably by means of a stainless steel brush.

Welding filler

The use of the following fillers is recommended for gas-shielded welding methods:

Welding rods and wire electrodes:

VDM® FM 59 (material no. 2.4607)

UNS N06059 AWS A5.14: ERNiCrMo-13

DIN EN ISO 18274: S Ni 6059 (NiCr23Mo16)

Welding parameters and influences

It must be ensured that work is carried out using targeted heat application and low heat input as listed in Table 6 as an example. The stringer bead technique is recommended. The interpass temperature should not exceed 120°C. In principle, checking of welding parameters is necessary.

Heat input Q can be calculated as follows:

$$Q = \frac{U \cdot I \cdot 60}{v \cdot 1,000} \left(\frac{\text{kJ}}{\text{cm}} \right)$$

U = arc voltage, volts

I = welding current strength, amperes

v = welding speed, cm/min

| Thick- ness | Welding pro- cess | Filler material | | Root pass ¹⁾ | | Intermediate and final passes | | Welding speed | Shielding gas | |
|----------------|---------------------------------|------------------------------|-------------------|-------------------------|----------|----------------------------------|----------|------------------|---|------------------|
| | | Diameter mm (in) | Speed (m/min.) | I in (A) | U in (V) | I in (A) | U in (V) | | Type | Rate (l/min.) |
| 3 (0.118) | m-TIG | 2 (0.0787) | - | 90 | 10 | 110-120 | 11 | 15 | I1, R1 with max 3% H ₂ | 8-10 |
| 6 (0.236) | m-TIG | 2-2,4 (0.0787- 0.0945) | - | 100-110 | 10 | 120-140 | 12 | 14-16 | I1, R1 with max 3% H ₂ | 8-10 |
| 8 (0.315) | m-TIG | 2.4 (0.0945) | - | 100-110 | 11 | 130-140 | 12 | 14-16 | I1, R1 with max 3% H ₂ | 8-10 |
| 10 (0.394) | m-TIG | 2.4 (0.0945) | - | 100-110 | 11 | 130-140 | 12 | 14-16 | I1, R1 with max 3% H ₂ | 8-10 |
| 3 (0.118) | Autom.-TIG ²⁾ | 1.2 (0.0472) | 1.2 | - | - | 150 | 11 | 25 | I1, R1 with max 3% H ₂ | 12-14 |
| 5 (0.197) | Autom.-TIG ²⁾ | 1.2 (0.0472) | 1.4 | - | - | 180 | 12 | 25 | I1, R1 with max 3% H ₂ | 12-14 |
| 2 (0.0787) | Autom. TIG (HD) | 1 (0.0394) | - | - | - | 180 | 11 | 80 | I1, R1 with max 3% H ₂ | 12-14 |
| 10 (0.394) | Autom. TIG (HD) | 1.2 (0.0472) | - | - | - | 220 | 12 | 40 | I1, R1 with max 3% H ₂ | 12-14 |
| 4 (0.157) | Plasma ³⁾ | 1,2 (0.0472) | 1 | 180 | 25 | - | - | 30 | I1, R1 with max 3% H ₂ | 30 |
| 6 (0.236) | Plasma ³⁾ | 1,2 (0.0472) | 1 | 200-220 | 25 | - | - | 26 | I1, R1 with max 3% H ₂ | 30 |
| 8 (0.315) | GMAW ⁴⁾ (MIG/Mag) | 1.0 (0.0394) | 6-7 | - | - | 130-140 | 23-27 | 24-30 | I1, I3- ArHe30, Z-ArHeHC 30/2/0.12 | 18 |
| 10 (0.394) | GMAW ⁴⁾ (MIG/MAG) | 1.2 (0.0472) | 6-7 | - | - | 130-150 | 23-27 | 25-30 | I1, I3- ArHe30, Z-ArHeHC 30/2/0.12 | 18 |

Information

¹⁾ Root pass: it must be ensured that there is sufficient root protection, for example using Ar 4.6, for all inert gas welding processes.

²⁾ Autom. TIG: the root pass should be welded manually (see manual TIG parameters)

³⁾ Plasma: recommended plasma gas Ar 4.6 / plasma quantity 3.0-3.5 l/min

⁴⁾ GMAW (MIG/MAG): the use of multi-component shielding gases is recommended for MAG welding.

Section energy kJ/cm: autom. TIG-HD max. 6; TIG, GMAW (MIG/MAG) manual, mechanized max. 8; plasma max. 10

The values are intended as guidance to simplify the setting of welding machines.

Table 6 – Welding parameters

Availability

VDM® Alloy 59 is available in the following standard semi-finished forms:

Sheet/Plate

Delivery condition: Hot or cold rolled, heat treated, descaled or pickled

| Condition | Thickness mm (in) | Width mm (in) | Length mm (in) | Piece Weight |
|-------------|----------------------|------------------|-------------------|-----------------------|
| Cold rolled | 1-7 (0.039-0.275) | ≤ 2,500 (98.42) | ≤ 12,500 (492) | |
| Hot rolled* | 3-55 (0.11-2.165) | ≤ 2,500 (98.42) | ≤ 12,500 (492) | ≤ 2.100 kg (4,630 lb) |

Strip

Delivery condition: Cold rolled, heat treated, pickled or bright annealed

| Thickness mm (in) | Width mm (in) | Coil-inside diameter mm (in) | | | |
|----------------------------------|------------------------|---------------------------------|---------------|---------------|---------------|
| 0,025-0,15 (0.000984-0.00591) | 4-230 (0.157-9.06) | 300 (11.8) | 400 (15.7) | 500 (19.7) | – |
| 0,15-0,25 (0.00591-0.00984) | 4-720 (0.157-28.3) | 300 (11.8) | 400 (15.7) | 500 (19.7) | – |
| 0,25-0,6 (0.00984-0.0236) | 6-750 (0.236-29.5) | – | 400 (15.7) | 500 (19.7) | 600 (23.6) |
| 0,6-1 (0.0236 -0.0394) | 8-750 (0.315-29.5) | – | 400 (15.7) | 500 (19.7) | 600 (23.6) |
| 1-2 (0.0394-0.0787) | 15-750 (0.591-29.5) | – | 400 (15.7) | 500 (19.7) | 600 (23.6) |
| 2-3 (0.0787-0.118) | 25-750 (0.984-29.5) | – | 400 (15.7) | 500 (19.7) | 600 (23.6) |

Rolled sheet – separated from the coil – are available in lengths from 250-4,000 mm (9.84 to 157.48 in).

Rod

Delivery condition: Forged, rolled, drawn, heat treated, oxidized, descaled or pickled, turned, peeled, ground or polished

| Dimensions | Outside diameter mm (in) | Length mm (in) |
|------------------------------|-----------------------------|---------------------------|
| General | 6-800 (0.236-31.5) | 1,500-12,000 (59.1 – 472) |
| Material specific dimensions | 8-450 (0.315-17.7) | 1,500-12,000 (59.1 - 472) |

Further shapes and dimensions on request

Wire

Delivery condition: Drawn bright, ¼ hard to hard, bright annealed in rings, containers, on spools and headstocks

| Drawn mm (in) | Hot rolled mm (in) |
|----------------------|-----------------------|
| 0.16-10 (0.006-0.04) | 5.5-19 (0.22-0.75) |

Other shapes and dimensions such as discs, rings, seamless or longitudinally welded pipes and forgings can be requested.

Publications

The following technical literature has been published about the material VDM® Alloy 59:

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