VDM Metals

A company of ACERINOX

VDM® Alloy 751

Nicrofer 7016 TiAl

Material Data Sheet No. 4047 **Revision 01**

November 2020

VDM® Alloy 751

Nicrofer 7016 TiAl

VDM® Alloy 751 is an age-hardenable nickel-chromium-iron alloy. The hardenability is obtained by means of addition of titanium, niobium and aluminum that form strengthening precipitates during heat treatment. It can be delivered in a solution-annealed or hardened condition. It is generally used in the age-hardened condition.

VDM® Alloy 751 is characterized by:

- High tensile strength up to 600 °C (1,110 °F)
- High creep and fatigue strength up to 820 °C (1,510 °F)
- High oxidation resistance up to 980 °C (1,795 °F)
- Excellent mechanical properties in low temperature environments
- Good corrosion resistance in high and low temperatures and high resistance against stress corrosion
- Good weldability (resistance and fusion welding)

Designations and Standards

Standard	Material designation
EN	2.4694 NiCr16Fe7TiAl
UNS	N07751

Table 1 – Designations and standards

Chemical Composition

	Ni	Cr	C	S	Mn	Si	Ti	Nb	Cu	Fe	Al
Min.	70	14					2	0.7		5	0.9
Max.		17	0.10	0.01	1	0.5	2.6	1.2	0.5	9	1.5
Due to technical reasons the alloy may contain additional elements											

Table 2 – Chemical composition (%)

Physical properties

Density	Melting range	Relative magnetic permeability at 20 °C (68 °F)	Curie Temperatur
8.2 g/ cm^3 bei 20 °C 512 lb/ft^2 at 68 °F	1,390 – 1,430 °C 2,530 – 2,610 °F	1.0035	-223 °C (-369 °F)

Temperature		Specific heat capacity		Thermal conductivity		Electrical resistivity	Modulus of elasticity		Coefficient of thermal expansion	
°C	°F	$\frac{J}{kg \cdot K}$	$\frac{Btu}{lb \cdot °F}$	$\frac{W}{m \cdot K}$	$\frac{Btu \cdot in}{sq \cdot ft \cdot h \cdot °F}$	μΩ · cm	GPa	10^3 ksi	$\frac{10^{-6}}{K}$	$\frac{10^{-6}}{°F}$
20	68	431	0.103	10.5	72.8	123	213	30.9		
100	212	460	0.11	11.8	81.8	125			13.2	7.33
200	392	480	0.115	13.4	92.9	127	189	27.4	13.5	7.5
300	572	500	0.119	15.0	104.	128			13.7	7.61
400	752	520	0.124	16.5	114	130	194	28.1	13.9	7.72
500	932	535	0.128	18.0	125	131			14.2	7.89
600	1,112	560	0.134	19.8	137	130	180	26.1	14.8	8.22
700	1,292	600	0.143	21.5	149	129	172	24.9	15.2	8.44
800	1,472	660	0.158	23.3	162	129	161	23.6	15.8	8.78
900	1,652	750	0.179	25.2	175	127	144	20.9	16.5	8.17
1,000	1,832			27.2	189	126			17.3	9.61

Table 3 – Typical physical properties (at room and elevated temperatures)

Microstructural properties

VDM® Alloy 751 has a cubic, face-centered crystal structure. The excellent mechanical strength is due to the precipitation hardening in the gamma phase (γ) by formation of the gamma prime phase (γ') along with some carbides during the hardening heat treatment.

Mechanical properties

The following mechanical properties apply to VDM® Alloy 751 in the solution-annealed and quenched condition.

Temperature		Yield strength $R_{p\ 0,2}$		Tensile strength R_m		Elongation at fracture A
°C	°F	MPa	ksi	MPa	ksi	%
20	68	716	104	1080	156	24
200	212	670	97.2	1020	148	27
400	392	652	94.6	983	143	30
600	572	660	95.7	912	132	25
700	752	660	95.7	861	125	14
800		534	77.5	637	92.4	12
900		271	39.3	35	5.08	29

Table 4a – Typical mechanical properties of solution-annealed and precipitation hardened VDM® Alloy 751 at room and elevated temperatures

Temperature		Yield strength $R_{p\ 0,2}$		Tensile strength R_m		Elongation at fracture A
°C	°F	MPa	ksi	MPa	ksi	%
20	68	391	56.7	782	113	42
200	212	380	55.1	700	102	44
400	392	371	53.8	640	92.8	47
600	572	360	52.2	600	87	47
700	752	350	50.8	593	86	17
800		340	49.3	577	83.7	7
900		243	35.2	316	45.8	34
1,000		73	10.6	78	11.3	

Table 4b – Typical mechanical properties of solution-annealed VDM® Alloy 751 at room and elevated temperatures

Corrosion resistance

VDM® Alloy 751 demonstrates an excellent corrosion resistance in high and low temperatures and the alloy furthermore has a high resistance against stress corrosion. The resistance against oxidizing conditions is remarkably high at up to 980 °C (1,800 °F).

Applications

Due to its high strength up to 820 °C (1,508 °F) and its excellent corrosion resistance, VDM® Alloy 751 can be used in a wide range of applications. A typical application is exhaust valves of combustion engines.

Fabrication and heat treatment

VDM® Alloy 751 can be easily deformed both hot and cold and can also be machined. However, for all processing, machines are required that take the mechanical properties like the high strength and characteristic work hardening rates into account. The deformation should preferably take place in the solution-annealed condition.

Heating

It is important that the workpieces are clean and free of any contaminations 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 0.1 wt.-% of sulfur. Heating oil with a maximum sulfur content of 0.5 wt.-% is also suitable. Electric furnaces are preferable for their precise temperature control and a lack of contaminations from fuels. The furnace temperature should be set between neutral and slightly oxidizing and it should not change between oxidizing and reducing. The workpieces must not come into direct contact with flames.

Hot forming

VDM® Alloy 751 can be optimally hot formed in a temperature range between 1,200 and 980 °C (2,190 and 1,800 °F) with subsequent rapid cooling down. For heating up, the workpieces are placed in the furnace that is heated up to the hot forming temperature. Once the temperature has equalized, a retention time of at least 60 minutes for each 100 mm of workpiece thickness should be observed. After this, the workpieces are removed immediately and deformed within the specified temperature window. When falling below a temperature of 980 °C (1,800 °F), the workpiece should be heated up as described above, as it would be too firm for further hot forming otherwise. Heat treatment after hot forming is recommended for the optimization of mechanical properties and corrosion resistance. To ensure good mechanical properties, the last deforming step should be at least 20% and not exceed a temperature of 1,100 °C (2,012 °F).

Cold forming

VDM® Alloy 751 is cold formed ideally in the solution-annealed state. The material has a significantly higher work hardening rate than austenitic stainless steels. This must be taken into account for the design and selection of forming tools and equipment, and for the planning of forming processes.

Heat treatment

In general, the heat treatment of VDM® Alloy 751 consists of two stages:

1. Solution annealing between 980 and 1,010 °C (1,796 and 1,850 °F) for min. 0.5 hours, followed by rapid cooling down.
2. Hardening annealing between 700 - 780 °C (1,292 - 1,436 °F) for 2-4 hours followed by air cooling.

For every heat treatment, the material should be inserted into the furnace already heated up to the annealing temperature and the information provided in the section “Heating” should be observed. For strip and wire products, the heat treatment can be performed in a continuous furnace at a speed and temperature that is adapted to the material thickness.

Descaling and pickling

High-temperature materials develop a protective oxide layer in service. The necessity for descaling should therefore be checked when placing the order. Oxides of VDM® Alloy 751 and heat tints in the area around welds adhere more strongly than in stainless steels. Grinding using extremely fine abrasive belts or grinding discs is recommended. Heat tints caused by grinding (grinding burns) are to be avoided. If pickling is required, the pickling times (as for all high-temperature materials) should be kept short because they can otherwise suffer from inter-crystalline corrosion attack. Furthermore, the temperature of the pickling line must be checked. Before pickling in nitric-hydrofluoric acid mixtures, dense oxide layers should be destroyed by blasting or grinding, or pre-treated in salt baths.

Machining
While VDM® Alloy 751 in the solution-annealed condition is easier to process and the strain on tools is less, better surface quality is achieved in the hardened condition. The best results in terms of the surface quality and dimensional accuracy of the finished product are achieved by pre-treatment before hardening and by finishing in the hardened condition. Because of the increased propensity for work hardening in comparison to low-alloy austenitic stainless steels, a lower cutting speed should be selected and the cutting tool should stay engaged at all times. An adequate chip depth is important in order to cut below a previously formed work-hardened zone.

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 workplace arranged separately must be provided that is specifically cordoned off from areas where C steel is being processed. 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 from iron particles being pressed in, 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 case of the latter, however, the cut edge (seam flank) must be reworked cleanly. Careful grinding without overheating is also permissible.

Striking the arc
Striking the arc may only take place in the seam area, e.g. 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 openings and root gaps (1 to 3 mm) are required to meet these properties. Due to the viscosity of

the welding material (compared to standard austenites) and the tendency to shrink, included angles of 60 to 70° – as shown in Figure 1 – have to be provided for butt welds.

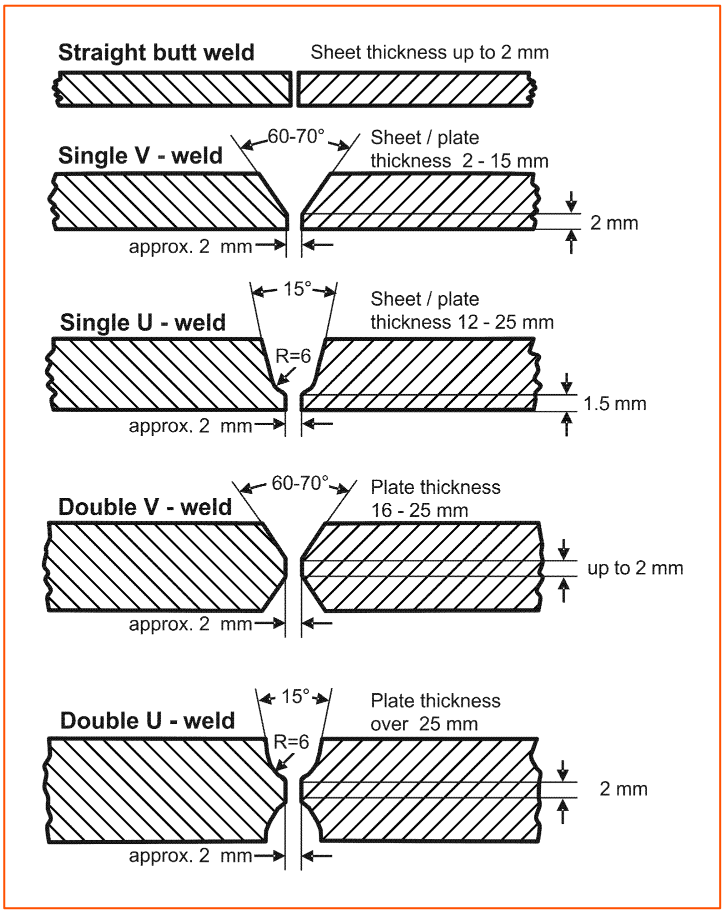

Figure 1 – Edge preparations for welding nickel alloys and special stainless steels

Cleaning

The basic material in the seam area (both sides) and the filler material (e.g. welding rod) should be cleaned with acetone.

Welding technique

VDM® Alloy 751 can be welded with a number of different welding techniques. If the metal shielding gas welding technique (MSG) is applied, the impulse technique is preferable. The material should be in its solution-annealed condition for welding and it should be free from scale, grease and markings. When welding the root, the root should be protected in the best possible way (e.g. argon 4.6), so that the welding edge is free from oxides after welding the root. Any heat tints must be removed, preferably using a stainless steel brush, while the welding edge is still hot.

Welding filler

VDM® FM 82 (Material no. 2.4806)
UNS N06082; AWS A5.14: ERNiCr-3;
DIN EN ISO 18274 - S Ni 6082 (NiCr20Mn3Nb)

VDM® FM 617 (Material no. 2.4627)
UNS N06617; AWS A5.14: ERNiCrCoMo-1;
DIN EN ISO 18274 - S Ni6617(NiCr22Co12Mo9)

It should be noted that the basic material (as described above) can be hardened, whereas the specified filler materials cannot. This results in the weld metal having a lower strength than the hardened basic material VDM® Alloy 751.

Welding parameters and influences

It must be ensured that work is carried out with a targeted heat application and low heat input as listed in the examples in Table 5. The stringer bead technique is recommended. The interpass temperature should not exceed 100 °C. In principle, continuous checking of welding parameters is necessary.

The section energy E can be calculated as follows:

E = U x I x 60 /v x 1000 (kJ/cm)

U = arc voltage, volts
I = welding current strength, amperes
v = welding speed, cm/minute

Post-treatment

If the work is performed optimally, brushing immediately after welding, i.e. while still warm and without additional pickling, will result in the desired surface condition. In other words, heat tints can be removed completely. Pickling, if required or specified, should generally be the last work step in the welding process. The information contained in the section entitled "Descaling and pickling" must be observed. Heat treatments are normally neither required before nor after welding.

Thickness	Welding techniques	Filler metal diameter	Welding speed	Root pass[1)]		Intermediate and final passes		Welding speed	Shielding gas
mm (in)		mm (in)	(m/min.)	I in (A)	U in (V)	I in (A)	U in (V)	(cm/min.)	Quantity (l/min.)
3 (0.118)	v-GTAW[2)]	1,2 (0.0472)	1,2			≤ 150	11	25	12-14
5 (0.197)	v-GTAW[2)]	1,2 (0.0472)	1,4			≤ 180	12	25	12-14
3 (0.118)	m-GTAW	2,0 (0.079)		90	10	110-120	11	15	8-10
6 (0.236)	m-GTAW	2,0-2,4 (0.079-0.0945)		100-110	10	120-140	12	14-16	8-10
8 (0.315)	m-GTAW	2.4 (0.0945)		100-110	11	130-140	12	14-16	8-10
10 (0.394)	m-GTAW	2.4 (0.0945)		100-110	11	130-140	12	14-16	8-10

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

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

This information serves as guidance to simplify the setting of welding machines.

Table 5 - Welding parameters

Availability

VDM® Alloy 751 is available in the following semi-finished forms:

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 (0.00096 – 0.006)	4-230 (0.16 – 9.06)	300 (11.8)	400 (15.7)	500 (19.7)	–
0.15-0.25 (0.006-0.01)	4-720 (0.16-28.34)	300 (11.8)	400 (15.7)	500 (19.7)	–
0.25-0.6 (0.01-0.024)	6-750 (0.24-29.5)	–	400 (15.7)	500 (19.7)	600 (23.06)
0.6-1 (0.024-0.04)	8-750 (0.32-29.5)	–	400 (15.7)	500 (19.7)	600 (23.6)
1-2 (0.04-0.08)	15-750 (0.6-29.5)	–	400 (15.7)	500 (19.7)	600 (23.6)
2-3 (0.08 – 0.118)	25-750 (0.98-29.5)	–	400 (15.7)	500 (19.7)	600 (23.6)
Rolled sheet – separated from the coil- are available in lengths from 250 to 4,000 mm (9,84 to157,48 in) .					

Rod and bar

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

Dimensions	External diameter mm (in)	Length mm (in)
General dimensions	6-800 (0.24 – 31.5)	1,500-12.000 (59.1-472)
Material specific dimensions	8-120 (0.31 – 4.72)	1,500-12.000 (59.1- 472)

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 (0.0063 – 0.394)	5.5-19 (0.0217 – 0.748)

Other shapes and dimensions (such as discs, rings, seamless or longitudinally welded pipes and forgings) can be re-quested.

Imprint

23 November 2020

Publisher
VDM Metals International GmbH
Plettenberger Straße 2
58791 Werdohl
Germany

Disclaimer
All information contained in this data sheet is based on the results of research and development work carried out by VDM Metals International GmbH and the data contained in the specifications and standards listed available at the time of printing. The information does not represent a guarantee of specific properties. VDM Metals reserves the right to change information without notice. All information contained in this data sheet is compiled to the best of our knowledge and is provided without liability. Deliveries and services are subject exclusively to the relevant contractual conditions and the General Terms and Conditions issued by VDM Metals. Use of the most up-to-date version of this data sheet is the responsibility of the customer.

VDM Metals International GmbH
Plettenberger Straße 2
58791 Werdohl
Germany

Phone +49 (0)2392 55 0
Fax +49 (0)2392 55 22 17

vdm@vdm-metals.com
www.vdm-metals.com