VDM Metals
A company of ACERINOX

VDM® Alloy 625
Nicrofer 6020 hMo

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VDM® Alloy 625

Nicrofer 6020 hMo

VDM® Alloy 625 is a nickel-chromium-molybdenum-niobium alloy with excellent resistance to a variety of corrosive media. In the soft annealed condition (grade 1; annealed at 950 to 1,050 °C (1,742 to 1,922 °F)), the alloy is used for wet corrosion applications and is approved by TÜV for pressure vessels in a temperature range from -196 to 450 °C (-320 to 842 °F). For high temperature applications above 600 °C (1,112 °F), the solution annealed variant (grade 2; annealed at 1,080 to 1,160 °C (1,976 to 2,120 °F)) is generally used. The strength of VDM® Alloy 625 can be enhanced by heat treatment.

VDM® Alloy 625 is also approved by ASME in both the grade 1 and grade 2 conditions for sections I, III, VIII and XII at temperatures defined in ASME Section IID (temperature limits vary by construction code).

VDM® Alloy 625 in the soft annealed condition **(grade 1)** is characterized by:

- Exceptional resistance to pitting, crevice corrosion, erosion and intergranular corrosion
- Immunity to chloride-induced stress corrosion cracking
- Good resistance to mineral acids such as nitric, phosphoric, sulfuric and hydrochloric acid
- Good resistance to alkalis and organic acids
- Good mechanical properties

VDM® Alloy 625 in the solution annealed condition **(grade 2)** is characterized by:

- Excellent creep strength above about 600 °C (1,112 °F)
- Good resistance to many types of hot gas corrosion, particularly chlorination

Designations

Standard	Material designation
EN	2.4856 - NiCr22Mo9Nb
ISO	NC22DNb
UNS	N06625
AFNOR	NC22DNb

Standards

Product form	DIN	DIN EN	ISO	ASME	ASTM	(SAE) AMS	VdTÜV	NACE	Others
Rod, bar	17744 17752	10228		SB 446	B 446 B 564 E 112	2154 C 5666	499		
Sheet, plate	17744 17750	6208 9722	15156-3	SB 443	B 443	5599	499	MR 0175 MR 0103	API 5LD
Strip	17744	2662	6208	SB 443	B 443	5599 5869	499	MR 0175	API 5LD
Wire	17744 17753	10088-3 10095							

Table 1 – Designations and standards

Chemical composition

	Ni	Cr	Fe	C[1)]	Mn	Si	Co	Al	Ti	P	S	Mo	Nb + Ta
Min.	58	21										8	3.2
Max.	71	23	5	0.03	0.5	0.4	1	0.4	0.4	0.01	0.01	10	3.8

[1)] The chemical analysis may differ slightly in some elements in other specifications and contain additional elements; according to DIN EN 10095 for example, the value for C is 0.03 to 0.10 wt.-% and the value for Cu is 0.50 wt.-% max; UNS specifies C as 0.10 wt-% max. and other elements are also different.

Table 2 – Chemical composition (wt.-%) according to VdTÜV data sheet 499

Physical Properties

Density	Melting range	Relative magnetic permeability at 20 °C (68 °F)
8.47 g/cm³ (0.306 lb/in³)	1,290-1,350 °C (2,354-2,462 °F)	1.003 (Maximum)

Temperature		Specific heat		Thermal conductivity		Electrical resistivity	Modulus of elasticity		Coefficient of thermal expansion	
°C	°F	J / Kg · K	Btu / lb · °F	W / m · K	Btu · in / sq. ft · h · °F	µΩ · cm	GPa	10³ ksi	10^{-6} / K	10^{-6} / °F
20	68					125	209	30.3		
100	212	496	0.118	12.4	86	126	202	29.3	12.51	7
200	392	521	0.124	14.2	98.5	127	195	28.3	13.03	7.2
300	572	538	0.128	16	110.9	129	190	27.6	13.34	7.4
400	762	555	0.133	17.7	122.7	131	185	26.8	13.62	7.6
500	932	573	0.137	19.3	133.8	132	178	25.8	13.94	7.7
600	1,112	620	0.148	21.5	149.1	131	170	24.7	14.47	8
700	1,292	654	0.156	26.8	185.8	130	162	23.5	15.16	8.4
800	1,472	663	0.158	26.8	185.8	129	153	22.2	15.68	8.7
900	1,652	677	0.162	26.7	185.1	128	142	20.6	16.17	9
1,000	1,832	684	0.163	28.2	195.5	128	128	18.6	16.63	9.2
1,100	2,012	695	0.166	29.6	205.2					
1,200	2,192	705	0.168							

Table 3 – Typical physical properties at room temperature and elevated temperatures

Microstructural properties

VDM® Alloy 625 has a cubic face centered lattice.

Mechanical properties

The following properties are applicable to VDM® Alloy 625 at room temperature and elevated temperatures in the indicated size ranges.

Temperature		Yield strength $R_{p\ 0.2}$		Tensile strength R_m		Elongation A
°C	°F	MPa	ksi	MPa	ksi	%
20	68	330	47.9	730	105.9	35
100	212	290	42.1	600	87	
200	392	265	38.4	580	84.1	
300	572	260	37.7	560	81.2	
400	752	260	37.7	540	78.3	
450	842	255	37	530	76.9	
500	932	265	38.4	650	94.3	
550	1,022	260	37.7	645	93.5	
600	1,112	255	37	640	92.8	
650	1,202	245	35.5	625	90.6	
700	1,292	240	34.8	610	88.5	
750	1,382	225	32.6	570	82.7	
800	1,472	215	31.2	450	65.3	
850	1,562	200	29	350	50.8	
900	1,652	190	27.6	250	36.3	
1,000	1,832	100	14.5	120	17.4	

Table 4 – Minimum short-time mechanical properties at room temperature and at elevated temperatures for VDM® Alloy 625 according to VdTÜV data sheet 499 (above 500 °C typical values)

Product form	Dimensions mm	Yield strength $R_{p\ 0.2}$ MPa	Tensile strength R_m MPa	Elongation A %
Strip, sheet	≤ 7	≥ 400	≥ 830	≥ 30
Sheet, plate	≤ 50	≥ 380	≥ 760	≥ 35
Forging	< 160	≥ 380	≥ 760	≥ 30
	≥ 160	≥ 330	≥ 730	≥ 35

Table 5 – Minimum mechanical properties at room temperature according to VdTÜV data sheet 499

Temperature		Time yield limit		Creep rupture strength	
		$R_{p\ 1.0}/10^4$ h	$R_{p\ 1.0}/10^5$ h	$R_m/10^4$ h	$R_m/10^5$ h
°C	°F	MPa	MPa	MPa	MPa
600	1,112	390	162	440	302
650	1,202	215	145	275	190
700	1,292	128	78	170	110
750	1,382	68	42	98	62
800	1,472	38	23	57	34
850	1,562	20	11	30	14
900	1,652	11	5	14	6

Table 6 – Typical yield limit and creep rupture strength values of solution annealed VDM® Alloy 625 (grade 2)

ISO V-notch impact values

Average values at room temperature a_k: 125 J/cm^2
KV: 100 J

Corrosion resistance

Optimum corrosion resistance can only be obtained if the material is in the correct metallurgical condition and possesses a clean structure. Under these circumstances In the soft annealed condition VDM® Alloy 625 (grade 1) has excellent corrosion resistance to a variety of corrosive media:

- Excellent resistance to pitting and crevice corrosion in chloride-containing media
- Virtual immunity to chloride-induced stress corrosion cracking
- High resistance to corrosion attack by mineral acids such as nitric, phosphoric, sulfuric, and hydrochloric acid; as well as by concentrated alkalis and organic acids, both under oxidizing as reducing conditions
- Very good resistance in seawater and brackish water, even at elevated temperatures
- High resistance to intergranular corrosion after welding and heat treatment
- High resistance to erosion corrosion

In the solution annealed variant VDM® Alloy 625 (grade 2) is highly resistant to many corrosive gas atmospheres:

- Good resistance to carburizing and scaling under static and cyclic conditions
- Resistance to nitriding
- Good resistance to gases containing halogens, and hydrogen chloride

Material	Material No.	CPT	CCP	PREN (pitting resistance equivalent number)[1)]
316 Ti	1.4571	15	<0	24
904 L	1.4539	45	25	37
VDM® Alloy 926	1.4529	70	40	47
VDM® Alloy 33	1.4591	85	40	50
VDM® Alloy 625	2.4856	75	55	51

[1)] PRE = 1 (% Cr) + 3,3 (% Mo) + 20 (% N)

Table 7 – Critical pitting temperature (CPT) and critical crevice temperature (CCT) of VDM® Alloy 625 (grade 1) in comparison to high alloyed stainless steels in 10 % $FeCl_3$, x 6 H_2O

Applications

The soft annealed version of VDM® Alloy 625 (grade 1) is used in the oil and gas industry, the chemical process industry, marine engineering and environmental engineering. Typical applications include:

- Equipment for the production of super phosphoric acid
- Plants for the treatment of radioactive waste
- Production pipe systems and linings of risers in oil production
- Offshore industry and seawater exposed equipment
- Sea water piping in shipbuilding
- Stress corrosion cracking resistant compensators
- Furnace linings

The solution annealed variant of VDM® Alloy 625 (grade 2) is used for high temperature applications up to 1,000 °C (1,832 °F), acc. to ASME Code for Pressure Vessels. Typical applications include:

- Flaring systems in refineries and offshore platforms
- Recuperators and compensators for hot exhaust gases

VDM® FM 625 is used as a matching filler metal for corrosion-resistant coatings of less resistant steels (overlay welding). Typical applications include:

- Components in the oil and gas extraction
- Superheater tubes in waste incineration plants

Fabrication and heat treatment

VDM® Alloy 625 can readily be hot- and cold-worked and machined. However, machines are required for any operation that meet the high mechanical properties.

Heating

Workpieces must be clean and free of any contaminants before and during heat treatment. Sulfur, phosphorus, lead and other low-melting-point metals can lead to damages when heat treating VDM® Alloy 625. Sources of such contaminants include marking and temperature-indicating paints and crayons, lubricating grease and fluids, and fuels. Fuels should contain as little sulfur as possible. Natural gas should contain less than 0.1 wt.-% of sulfur. Heating oil with a sulfur content of maximum 0.5 wt.-% is also suitable. Electric furnaces are to be preferred due to precise temperature control and freedom from contamination due to fuel. The furnace atmosphere should be set between neutral and slightly oxidising, and should not change between oxidising and reducing. Direct flame impingement needs to be avoided.

Hot working

VDM® Alloy 625 may be hot worked in the temperature range 1,150 to 900 °C (2,100 to 1,650 °F) with subsequent rapid cooling down in water or by using air. The workpieces should be placed in the furnace heated to hot working temperature in order to heat up. Once the hot working temperature has been reached again, a retention time of 60 minutes for each 100 mm (4 in) of workpiece thickness is recommended. Afterwards, workpieces should be removed immediately and formed during the stated temperature window. If the material temperature falls to 950 °C (1,742 °F), the workpiece must be reheated.

Heat treatment after hot working is recommended in order to achieve optimum microstructure and corrosion resistance.

Cold working

Cold working should be carried out on annealed material. VDM® Alloy 625 has a higher work hardening rate than austenitic stainless steels. This must be taken into account during design and selection of forming tools and equipment and during the planning of the forming processes. Intermediate annealing may be necessary at high degrees of cold working deformation. After cold working with more than 15 % of deformation the material should be soft annealed (grade 1) or solution annealed (grade 2).

Heat treatment

VDM® Alloy 625 is used in applications where the operating temperatures are below 600 °C (1,112 °F) in the soft annealed condition (grade 1). The soft annealing is carried out at temperatures of 950 to 1,050 °C (1,742 to 1,922 °F); a temperature of 980 °C (1,796 °F) is preferred.

For applications above 600 °C (1,112 °F), the solution annealed variant of VDM® Alloy 625 (grade 2), which provides optimized creep strength, is used. The solution heat treatment should be carried out in the temperature range between 1,080 °C and 1,160° C (1,976 and 2,120 °F), preferably at 1,120 °C (2,048 °F).

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.

Water quenching should be carried out rapidly to achieve optimum corrosion characteristics. Workpieces of less than 3 mm (0.12 in) thickness can be cooled down using air nozzles. The workpiece has to be put into the pre-heated furnace. The furnace should be heated up to the maximum annealing temperature. The cleanliness requirements listed under ‘Heating’ must be complied with.

Descaling and pickling
Oxides of VDM® Alloy 625 and discoloration adjacent to welds are more adherent than on stainless steels. Grinding with very fine abrasive belts or discs is recommended. Care should be taken to prevent tarnishing. Before pickling in a nitric/hydrofluoric acid mixture, the surface oxide layer must be broken up by abrasive blasting or grinding or by pre-treatment in a fused salt bath. Particular attention should be paid to the pickling time.

Machining
VDM® Alloy 625 should be machined in the annealed condition. As the alloy is prone to work-hardening, low cutting speeds and appropriate feed rates should be used and the tool should be engaged at all times. Sufficient chip depths are important to get below the work-hardened surface layer. The optimum dissipation of heat through the use of large amounts of appropriate, preferably water containing cooling lubricants is crucial for a stable machining process.

Welding

When welding nickel-base alloys and special stainless steels, the following instructions should be adhered to:

Workplace
A separately-located workplace, which is specifically separated from areas in which carbon steels are being processed, should be used. Maximum cleanliness is required, and draughts should be avoided during inert gas welding.

Auxiliary equipment and clothing
Clean fine leather gloves and clean working clothes should be used.

Tools and machines
Tools used for other materials must not be used for nickel-base alloys and stainless steels. Brushes should be made of stainless materials. Processing and machining equipment such as shears, punches or rollers must be fitted with means (felt, cardboard, films) in order to avoid material contamination with ferrous particles, which can be pressed into the surface of the material and thus lead to corrosion.

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

Ignition
The arc may only be struck in the weld area, e.g. along the seam flanks or outlets, and should not be carried out on the workpiece surface. Arc striking areas are prone to corrosion.

Included angle

The different physical characteristics of nickel alloys and special stainless steels are generally expressed through lower thermal conductivity and higher thermal expansion in comparison with carbon steel. This should be allowed for by means of, among other things, wider root gaps or openings (1-3 mm; 0.04-1.2 in), while larger included angles (60-70°), as shown in Fig. 1, should be used for butt joints owing to the viscous nature of the molten weld metal and to counteract the pronounced shrinkage tendency.

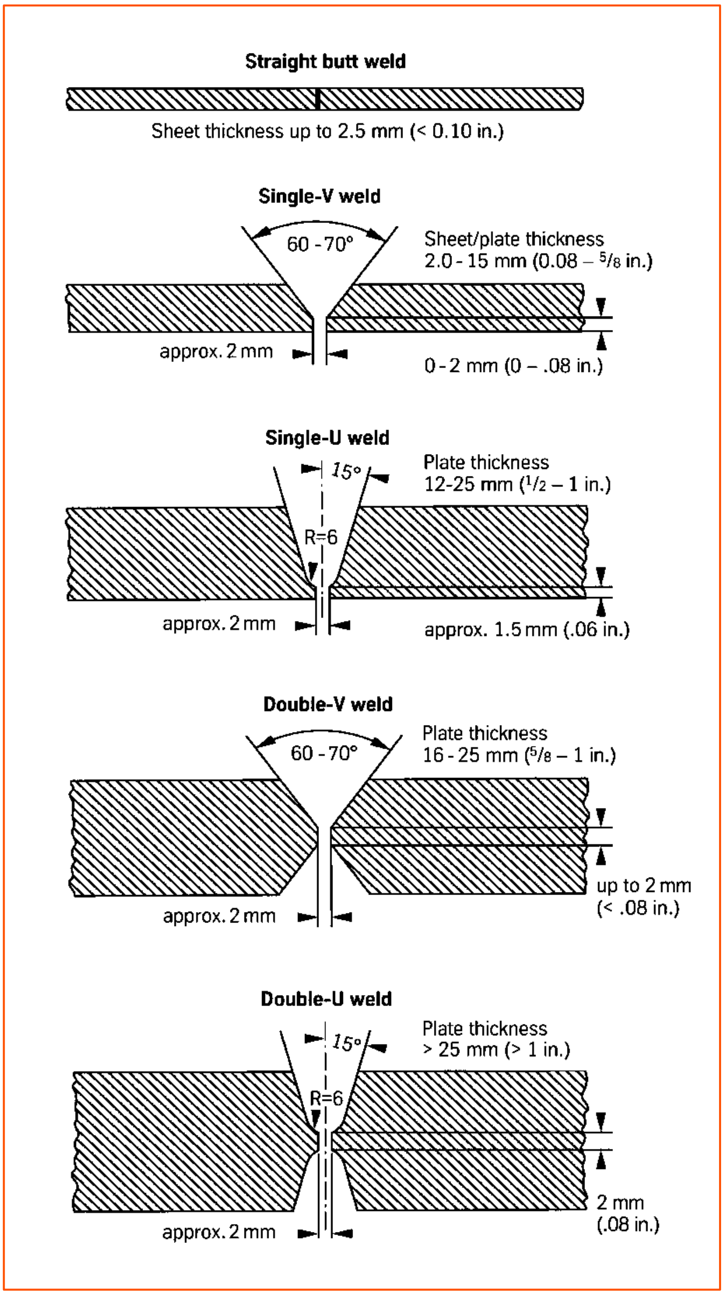

Figure 2 – Edge preparation for welding nickel alloys and special stainless steels

Cleaning

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

Welding process
VDM® Alloy 625 can be joined by all conventional welding processes. These include GTAW (TIG), TIG hot wire, plasma arc, GMAW (MIG/MAG) and MAG-Tandem, submerged arc welding and SMAW (MMA). For welding, VDM® Alloy 625 should be in the soft or solution annealed condition and be free from scale, grease and markings. Pulsed arc welding is the preferred technique. For the MAG process the use of a multi-component shielding gas (Ar + He + H2 + CO2) is recommended.

When welding roots, sufficient protection of the root needs to be ensured with pure argon (Ar 4.6) so that the welding seam is free of oxides after welding. Root backing is also recommended for the first intermediate pass following the initial root pass and in some cases even for the second pass, depending on the weld set-up.

Any discoloration/heat tint should be removed preferably by brushing with a stainless steel wire brush while the weld metal is still hot.

Filler metal
The following filler material is recommended:

Welding rods, welding wire and wire electrodes

VDM® FM 625 (W.-Nr. 2.4831)
DIN EN ISO 18274: S Ni 6602 (SG-NiCr 21 Mo 9 Nb)
UNS N06625
AWS A 5.14: ERNiCrMo-3

Welding strip for joint and overlay welding/cladding

VDM® FM 625/VDM® WS 625 (W.-Nr. 2.4831)
DIN EN ISO 18274: S Ni 6625/B Ni 6625
UNS N06625
AWS A5.14: ERNiCrMo-3/EQNiCrMo-3

Covered electrodes can be used.

Welding parameters and influences
Care should be taken that the work is performed with a deliberately chosen, low heat input as indicated in Table 6 by way of example. The stringer bead technique is recommended. The interpass temperature should not exceed 150 °C (302 °F). The welding parameters should be monitored as a matter of principle.

The heat input Q can be calculated as follows:

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

U = arc voltage, volts
I = welding current, amps
v = welding speed, cm/min.

Post-weld treatment
Brushing with a stainless steel wire brush immediately after welding, i.e. while the metal is still hot generally results in removal of heat tint and produces the desired surface condition without additional pickling. Pickling, if required or prescribed, however, would generally be the last operation performed on the weldment. Please also refer to the information on ‘Descaling and pickling’. Neither pre- nor postweld heat treatments are required. Preheating before welding is generally not necessary.

Thickness	Welding technique	Filler material		Root pass[1]		Intermediate and final passes		Welding speed	Shielding gas	
(mm)		Diameter (mm)	Speed (m/min)	I in (A)	U in (V)	I in (A)	U in (V)	(cm/min)	Type	Rate (l/min)
3	manual TIG	2		90	10	110-120	11	15	I1, R1 with max. 3 % H2	8-10
6	manual TIG	2-2,4		100-110	10	120-130	12	14-16	I1, R1 with max. 3 % H2	8-10
8	manual TIG	2,4		100-110	11	130-140	12	14-16	I1, R1 with max. 3 % H2	8-10
10	manual TIG	2,4		100-110	11	130-140	12	14-16	I1, R1 with max. 3 % H2	8-10
3	autom. TIG[2]	1,2	1,2	90	10	150	11	25	I1, R1 with max. 3 % H2	12-14
5	autom. TIG[2]	1,2	1,2	100-110	10	150	12	25	I1, R1 with max. 3 % H2	12-14
2	autom. TIG HD	1				180	11	80	I1, R1 with max. 3 % H2	12-14
10	autom. TIG HD	1,2		100-110	11	220	12	40	I1, R1 with max. 3 % H2	12-14
4	Plasma[3]	1,2	1	165	25			30	I1, R1 with max. 3 % H2	30
6	Plasma[3]	1,2	1	190-200	25			26	I1, R1 with max. 3 % H2	30
8	MIG/MAG[4]	1	6-7			130-140	23-27	24-30	I1	18
10	MIG/MAG[4]	1,2	6-7			130-150	23-27	25-30	I1	18

[1] It must be ensured that there is sufficient root protection, for example using Ar 4.6, for all inert gas welding processes.

[2] Root pass should be welded manually (please see 'manual TIG' for parameters).

[3] Recommended plasma gas I1, R1 at max. 3 % H2 / rate 3,0 bis 3,5 l/min

[4] For MAG welding the use of multicomponent inert gases is recommended.

Section energy kJ/cm:
TIG, MIG/MAG max. 8; MMA max.7; Plasma max. 10

Figures are for guidance only and are intended to facilitate setting of the welding machines.

Table 8 – Welding parameters

Availability

VDM® Alloy 625 is available in the following standard semi-finished product forms:

Rod and bar

Delivery conditions: forged, rolled, drawn, heat treated, oxidized, descaled resp. pickled, machined, peeled, ground or polished

Dimensions*	Outside diameter mm (in)	Length mm (in)
General dimensions	6-800 (0.24-31.5)	1,500-12,000 (59.06-472.44)
Material specific dimensions	12-600 (0.47-23.62)	1,500-12,000 (59.06-472.44)

* Further dimensions on request

Sheet and plate

Delivery conditions: hot or cold rolled, heat treated, descaled resp. pickled

Condition	Thickness mm (in)	Width mm (in)	Length mm (in)	Piece weight kg
Cold rolled	1-7 (0.04-0.28)	1,000-2,500 (39.4-98.43)	≤ 5,500 (216.54)	≤ 3,350
Hot rolled*	3-100 (0.12-3.94)	1,000-2,500 (39.4-98.43)	≤ 12,500 (492.13)	≤ 3,350

* 2 mm thickness on request

Strip

Delivery conditions: cold rolled, heat treated, pickled or bright annealed

Thickness mm (in)	Width mm (in)	Coil - inside diameter mm			
0.025-0.15 (0.001-0.0059)	4-230 (0.16-9.06)	300	400	500	–
0.15-0.25 (0.0059-0.01)	4-720 (0.16-28.34)	300	400	500	–
0.25-0.6 (0.01-0.024)	6-750 (0.24-29.5)	–	400	500	600
0.6-1 (0.024-0.04)	8-750 (0.32-29.5)	–	400	500	600
1-2 (0.04-0.08)	15-750 (0.6-29.5)	–	400	500	600
2-3 (0.08-0.12)	25-750 (0.98-29.5)	–	400	500	600

Wire

Delivery conditions: bright drawn, ¼ hard to hard, bright annealed in rings, containers, on spools and spiders

Drawn mm (in)	Hot rolled mm (in)
0.16-10 (0.006-0.4)	5.5-19 (0.22-0.75)

Other shapes and dimensions such as circular blanks, rings, seamless or longitudinal-welded tubes and pipes or forgings are subject to special enquiry.

Technical publications

The following articles were published on VDM® Alloy 625:

M. Köhler, U. Heubner: “Time-Temperature - Sensitization and Time-Temperature – Precipitation Behaviour of Alloy 625” in “NACE CORROSION ‘96”, Houston, Texas, 1996, S. 427/1-10.

M. Köhler: “Effect of Elevated-Temperature-Precipitation in Alloy 625 on Properties and Microstructure, Superalloys 718, 625 and Various Derivates”, TMS 1991, S. 363 – 374.

U. Brill, U. Heubner, K. Drehfahl, J. Henrich: „Zeitstandwerte von Hochtemperaturwerkstoffen“, Ingenieurwerkstoffe 3 1991, S. 59 – 62.

U. Brill, U. Heubner, M. Rockel: „Hochtemperaturkorrosion handelsüblicher hochlegierter austenitischer Werkstoffe im geschweißten und ungeschweißten Zustand“, Metall 44 1990, S. 936 – 946.

U. Heubner, M. Köhler: “Effect of Carbon Content and Other Variables on Yield Strength, Ductility and Creep Properties of Alloy 625, Superalloys 718, 625, 706 and Various Derivates”, TMS 1994, S. 479 – 488.

U. Heubner, M. Köhler: „Das Zeit-Temperatur-Ausscheidungs- und das Zeit-Temperatur-Sensibilisierungs-Verhalten von hochkorrosionsbeständigen Nickel-Chrom-Molybdän-Legierungen“, Werkstoffe und Korrosion 43 1992, S. 181 – 190.

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