VDM Metals

A company of ACERINOX

VDM® Crofer 22 APU

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VDM® Crofer 22 APU is a ferritic high-temperature stainless steel that has been specially designed for use in high-temperature fuel cells (SOFC). At temperatures of up to 900 °C a surface layer made of chrome manganese oxide, which has great thermodynamic stability and good electrical conductivity, forms on the surface of this alloy. The material's coefficient of thermal expansion matches the ceramics typically used in high-temperature fuel cells over the entire temperature range.

VDM® Crofer 22 APU is characterized by:

- Good corrosion resistance at high-temperatures in anode and cathode gas
- low rate of chromium evaporation
- good workability
- low coefficient of thermal expansion
- good electrical conductivity of the oxide layer electrical

Designations and standards

Standardization	Material designation
D	1.4760 X1CrTiLa22
UNS	S44535

Product form	ASTM
Sheet Metal	A 240
Strip	A 240

Table 1 – Designations and standards

Chemical composition

	C	Cr	Fe	S	Mn	Si	Ti	Cu	P	Al	La
Min.		20.0	Bal.		0.30		0.03				0.04
Max.	0.03	24.0		0.020	0.80	0.50	0.20	0.50	0.050	0.50	0.2
For technical reasons, the material may contain further chemical elements											

Table 2 – Chemical composition (%) according to ASTM A 240

Physical properties

Density	Melting range	
7.7 g/cm³ at 20 °C 481 lb/ft² at 68 °F	1,510 –1,530 °C 2,750 – 2,790 °F	The material is magnetic

Temperature		Specific heat capacity		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	10⁶ psi	10⁻⁶ / K	10⁻⁶ / °F
25	77	470	0.112	26	180	55	220	31.9		
200	392	520	0.124	23	159	70	210	30.5	10.3	5.72
400	752	610	0.146	23	159	90	195	28.3	10.8	6.0
500	932						183	26.5	11.2	6.22
600	1,112	910	0.217	30	208	105			11.4	6.33
700	1,292								11.6	6.44
800	1,472	660	0.158	24	166	115			11.9	6.61
900	1,652								12.3	6.81
1,000	1,832	650	0.155	27	187	120			12.7	7.06

Table 3 – Typical physical properties at room and elevated temperatures

Microstructural properties

VDM® Crofer 22 APU has a cubic body-centered structure.

Mechanical properties

The following mechanical properties apply to VDM® Crofer 22 APU in the solution-annealed condition

Temperature		Yield strength $R_{p\ 0.2}$		Tensile strength R_m		Elongation A
°C	°F	MPa	ksi	MPa	ksi	%
20	68	277	40.2	365	52.9	34
200	392	194	28.1	288	41.8	21
400	752	181	26.3	307	44.5	27
600	1,112	127	18.4	147	21.3	29
700	1,292	54	7.83	56	8.12	72
800	1,472	30	4.35	30	4.35	87

Table 4 – Typical mechanical properties at room and increased temperatures

Product form	Dimensions		Yield strength $R_{p\ 0.2}$		Tensile strength R_m		Elongation at fracture A	Hardness Rockwell
	mm	in	MPa	ksi	MPa	ksi	%	HRB[1)]
all	0.25 – 0.38	0.00984 to 0.015	≥ 250	36.6	≥ 350	50.8	≥ 20	70 - 90
all	≥ 0.38	≥0.015	≥ 250	36.6	≥ 350	50.8	≥ 25	70 - 90

1) Typical values for all products, shapes at room temperature

Table 5 – Mechanical minimum values in soft-annealed condition for all product shapes at room temperature

Product form	Yield strength $R_{p\ 0.2}$		Tensile strength R_m		Elongation at fracture A
	MPa	ksi	MPa	ksi	%
Sheet Metal	270	39.2	370	53.7	30
Strip	320	46.4	450	65.3	30
Wire	350	50.8	500	72.5	15

Table 6 – Typical mechanical properties for different product shapes at room temperature

Corrosion resistance

VDM® Crofer 22 APU shows excellent corrosion resistance up to 900 °C (1,652 °F) in the gas atmospheres, which occur during SOFC applications. The oxide layer on VDM® Crofer 22 APU is composed of a fine-grain internal scale layer, which consists mainly of Cr_2O_3, and of an external scale layer consisting of pillared $(Mn, Cr)_3O_4$ spinels. Chromium evaporation is very effectively reduced by the external scale layer. A very good oxidation resistance is achieved through the reduction of impurities.

Applications

VDM® Crofer 22 APU is used for interconnector plates for the separation of individual cells in a SOFC (= Solid Oxide Fuel Cell) fuel cells stack and also in a SOEC (Solid Oxide Electrolytic Cell) electrolytic cell stack.

Processing and Heat treatment

VDM® Crofer 22 APU can be easily hot and cold-formed with the normal industrial manufacturing techniques, and can also be machined.

Heat treatment
Workpieces must be clean and free of any contaminants before and during heat treatment.
Sulfur, phosphorus, lead and other low-melting point metals can cause damage during the heat treatment of VDM® Crofer 22 APU. This type of contamination can be contained in marking and temperature display paints or pins, and also in lubricating grease, oils, fuels and similar materials amongst others. Fuel sulfur content must be as low as possible. Natural gas should contain less than 0.1 wt.-% of sulfur. Heating oil with a sulfur content of maximum 0.5% in weight is suitable. Heat treatment should preferably be carried out in electric furnaces under vacuum or shielding gas due to the precise temperature control and freedom of impurities. Heat treatment in air or in gas-heated furnaces are also acceptable, as long as impurities are at a low level so that a neutral and easily oxidizing furnace temperature can be set.

A furnace temperature which alternates between oxidizing and reducing should be avoided. Workpieces should not be contacted directly by flames. Recrystallization annealing should be carried out after cold-forming. For strips as the product form, the heat treatment can be performed in a continuous furnace at a speed and temperature that is adapted to the strip thickness.

Descaling and pickling
Oxides of VDM® Crofer 22 APU and heat tint in the area around welds adhere more strongly than in standard stainless steels. Grinding using extremely fine abrasive belts or grinding discs is recommended. Heat tints should be avoided. Before pickling in nitric-hydrofluoric acid mixtures, the oxide layers should be destroyed by abrasive blasting or fine grinding, or pre-treated in salt baths. Particular attention must be paid to the pickling time and temperature of the pickle.

Welding information

Safety:
The generally applicable safety recommendations for avoiding dust and smoke explosions must be observed

Although welding VDM® Crofer 22 APU is not generally recommended as the joining method, the material can be welded for many applications using the TIG or laser technique, for example. In addition, soldering can be an alternative to welding. For welding, the material should be in the annealed condition and be free of scale, grease or markings. During welding, the greatest measure of cleanliness must be ensured and draught air has to be avoided. For welding VDM® Crofer 22 APU, the general information for nickel alloys and special stainless steels should be taken into account.

Availability

VDM® Crofer 22 APU is available in the following standard semi-finished forms:

Sheet

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

Delivery condition	Thickness mm (in)	Width mm (in)	Length mm (in)	Piece weight kg (lb)
Cold rolled	2-7 (0.0787 to 0.276)	1.000 – 2.500 (39.4 to 98.4)	≤ 12,500 (≤ 492)	≥ 1,300 (≥ 2,870)
Hot-rolled	3-25 (0.118 to 0.984)	1.000 – 2.500 (39.4 to 98.4)	≤ 12,500 (≤ 492)	≤ 1,300 (≥ 2,870)

Strip

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

Thickness mm (in)	Width mm (in)	Coil internal diameter mm (in)			
0.025-0.15 (0.000984 to 0.00591)	4-230 (0.157 to 9.06)	300 (11.8)	400 (15.7)	500 (19.7)	–
0.15-0.25 (0.00591 to 0.00954)	4-720 (0.157 to 28.3)	300 (11.8)	400 (15-7)	500 (19.7)	–
0.25-0.6 (0.00954 to 0.0236)	6-750 (0.236 to 29.5)	–	400 (15.7)	500 (19.7)	600 (23.6)
0.6-1 (0.0236 to 0.0787)	8-750 (0.315 to 29.5)	–	400 (15.7)	500 (19.7)	600 (23.6)
1-2 (0.0787 to 0.118)	15-750 (0.591 to 29.5)	–	400 (15.7)	500 (19.7)	600 (23.6)
2-3 0.0787 to 0.118)	25-750 (0.984 to 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 to 157,4 in).

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

Publications

The following technical publications have been published about the material VDM® Crofer 22 APU:

R. Hojda, W. Heimann, W. J. Quadakkers: Großserientaugliches Werkstoffkonzept für Hochtemperatur- Brennstoffzellen; ThyssenKrupp techforum, July 2003.

R. Hojda: Großserientaugliches Werkstoffkonzept für Brennstoffzellen; SCOPE - Das moderne Industrie-Magazin, April 2004.

R. Hojda, W. J. Quadakkers: Verbessertes Produkt VDM® Crofer 22 APU; special print SD 1/05 from ThyssenKrupp techforum, July 2005.

R. Hojda, L. Paul: UNS S44535 alloy development for interconnect applications in solid oxide fuel cells; CORROSION 2006, Paper No. 06479, NACE International, Houston, 2006.

H. Hattendorf, L. Paul, L. Niewolak, V. Shemet, P. Ennis, W. Quadakkers: Practical aspects of using Crofer 22 APU for interconnects in Solid Fuel Cells; 2007 Fuel Cell Conference; San Antonio, Texas, October 2007.

P. Huczkowski, N. Christiansen, V. Shemet, J. Piron-Abellan, L. Singheiser, W. J. Quadakkers: Oxidation limited life times of chromia forming ferritic steels; 2004 Materials and Corrosion; 55, No. 11;.

B. Kuhn, C. Asensio Jimenez, L. Niewolak, T. Hüttel, T. Beck, H. Hattendorf, L. Singheiser, W. J. Quadakkers, Effect of Laves phase strengthening on the mechanical properties of high Cr ferritic steels for solid oxide fuel cell interconnect application, Materials Science and Engineering: A, Material Science and Engineering A 528 (2011) p 5888-5899.

Further publications regarding VDM® Crofer 22 APU and fuel cells (SOFC) are available from Forschungszentrum Jülich, Department IEF-2, D-52425 Jülich.

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