VDM Metals

A company of ACERINOX

VDM® Alloy 699 XA
Nicrofer 6830 Al

Data Sheet No. 4138

April 2024

VDM® Alloy 699 XA

Nicrofer 6830 Al

VDM® Alloy 699 XA is a high-temperature material with excellent resistance in carburizing / metal dusting conditions and a high creep and oxidation resistance up to 1,000 °C (1,832°F). VDM® Alloy 699 XA is delivered in the solution-annealed state with a descaled surface.

VDM® Alloy 699 XA is characterized by:

- High metal dusting resistance
- Outstanding resistance to oxidation at high temperatures
- Workability comparable to VDM® Alloy 601
- Creep resistance in the range of VDM® Alloy 601
- Good weldabilty under pure argon

Designations and standards

Standardisation	Material designation
D	2.4842 – NiCr30Al
UNS	N06699

Table 1a – Designations and standards

Designations and Standards

Product form	DIN	ASTM	ISO
Rod, bar	17742	B 166	
Sheet, plate	17742	B 168	
Strip	17742	**B 168**	
Wire	17742	B 166	
Filler material (solid wire, rods, strips)			18274

Table 1b – Designations and standards

Chemical composition

	Ni	Cr	Al	Fe	Mn	Si	Ti	Nb	Cu	Zr	C	N	P	S	B
Min.	Bal.	26.0	1.9								0.005				
Max.		30.0	3.0	2.5	0.50	0.50	0.60	0.50	0.50	0.10	0.10	0.05	0.020	0.01	0.008

Table 2 – Chemical composition (wt. %) according to UNS number N06699 and DIN 17742

Physical properties

Density	Melting range
8.02 g/cm³ at 20 °C 0.29 lb/in³ at 68 °F	1,370 – 1,390 °C 2,498 – 2,534 °F

Temperature		Specific heat capacity		Thermal conductivity		Modulus of elasticity		Coefficient of thermal expansion	
°C	°F	$\frac{J}{kg \cdot K}$	$\frac{Btu}{lb \cdot °F}$	$\frac{W}{m \cdot K}$	$\frac{Btu}{ft \cdot h \cdot °F}$	GPa	10^3 ksi	$\frac{10^{-6}}{K}$	$\frac{10^{-6}}{°F}$
20	68	440	0.105	10.5	6.1	208	30.2	13.8[1)]	7.66[1)]
100	212	469	0.112	11.9	6.9	204	29.5	13.9	7.73
200	392	497	0.119	13.6	7.9	197	28.6	14.1	7.83
300	572	518	0.124	15.3	8.8	191	27.8	14.3	7.93
400	752	533	0.127	16.9	9.8	185	26.8	14.5	8.05
500	932	545	0.130	18.3	10.6	179	25.9	14.7	8.17
600	1112	555	0.133	19.8	11.4	172	25.0	15.1	8.40
700	1292	637	0.152	24.3	14.0	165	23.9	15.9	8.83
800	1472	643	0.154	24.0	13.9	156	22.6	16.7	9.28
900	1652	646	0.154	25.4	14.7	147	21.3	17.1[1)]	9.51[1)]
1000	1832	648	0.155	26.4	15.3	137	19.9	17.5[1)]	9.74[1)]
1100	2012	650[1)]	0.155[1)]	27.4[1)]	15.8[1)]	127[1)]	18.5[1)]	18.0[1)]	9.98[1)]

[1)] extrapolated

Table 3 – Typical physical properties at room and elevated temperatures

Microstructural properties

VDM® Alloy 699 XA has a face-centered cubic lattice. Some $M_{23}C_6$ carbides form below 1,150 °C (2,102 °F) and γ' precipitations form below about 800 °C (1,472 °F).

Mechanical properties

The following properties are applicable to VDM® Alloy 699 XA in the solution-annealed condition at room and elevated temperatures.

Temperature		**Yield strength** $R_{p\ 0,2}$		**Tensile strength** R_m		**Elongation** A
°C	**°F**	**MPa**	**ksi**	**MPa**	**ksi**	**%**
20	68	240	35	610	89	40
100	212	210	30.5			
200	392	180	26.1			
300	572	160	23.2			
400	752	150	21.8			
500	932	143	20.7			
600	1,112	137	19.9			
700	1,292	120	17.4			

Table 4 – Minimum short-term properties of VDM® Alloy 699 XA (grain size ≥ 75 µm; ASTM < 4.5) at room and elevated temperatures, solution-annealed at 1,100 °C to 1,180 °C (2,012 °F 2,156 °F)

ISO V-notch impact strength

Minimum value for V-notch impact strength KV_2 (according to ISO 148-1) at 20 °C in the solution-annealed condition, grain size ≥ 75 µm (ASTM < 4.5):

≥ 70 Joule

Hardness

Typical Hardness after solution annealing, grain size ≥ 75 µm (ASTM < 4.5): 84 HRB

Creep resistance

The creep resistance of VDM® alloy 699 XA is in the range of VDM® Alloy 601. See Figure 1:

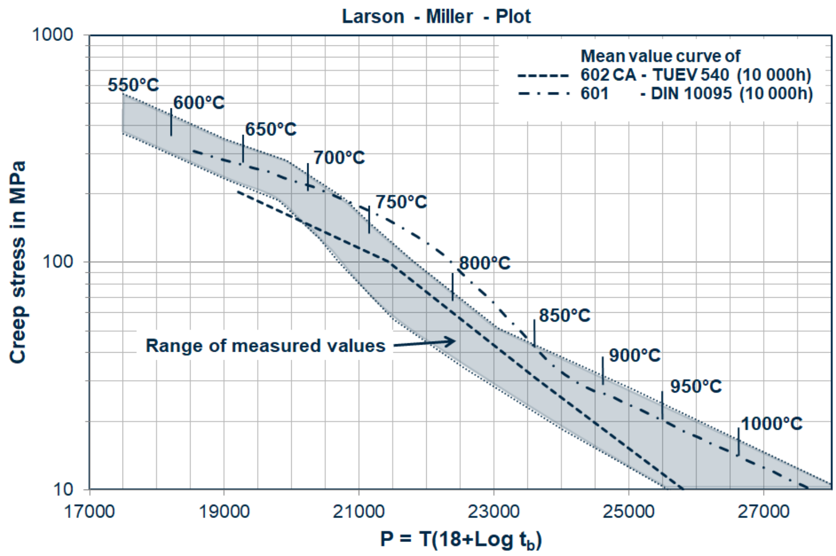

Figure 1 – Creep resistance of VDM® Alloy 699 XA for grain size ≥ 75 µm (ASTM < 4.5), T = absolute temperature, t_b = time to rupture

Corrosion resistance

VDM® Alloy 699 XA is especially characterized by a very high resistance against carburization / metal dusting and has in addition a good oxidation resistance, which is similar to VDM® Alloy 602 CA and better across the entire application range up to 1,000 °C (2,012 °F) compared to VDM® Alloy 601. Even under extreme conditions, such as cyclic heating and cooling, VDM® Alloy 699 XA retains this property, which is caused by a tight and adhering alumina layer, which is very resistant to chipping.

High temperature oxidation tests show that, compared to other high temperature materials, this material has the lowest mass loss under cyclic conditions.

The good resistance of VDM® Alloy 601 and VDM® Alloy 602 CA against carburization is increased even further by VDM® Alloy 699 XA due to the high chromium content, additions of aluminum and simultaneously low iron content. This applies especially to the metal dusting resistance of the material (see Figure 2).

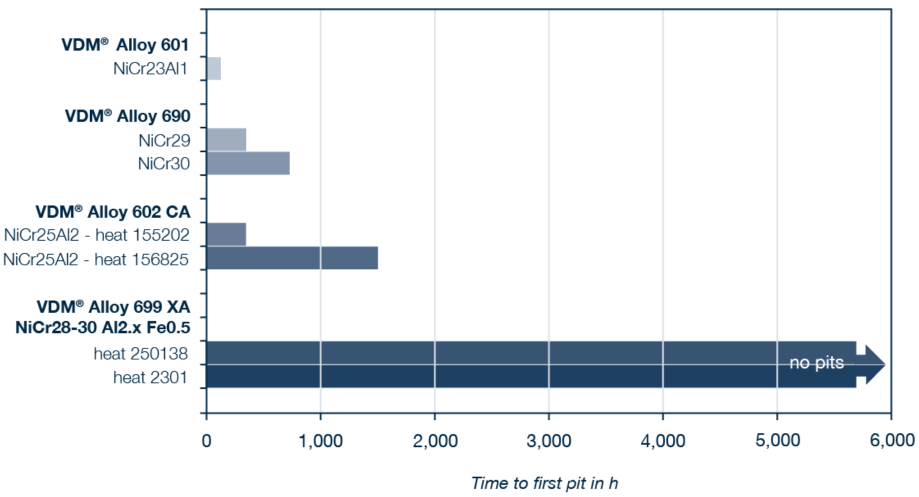

Figure 2 – Metal Dusting resistance of VDM® Alloy 699 XA in an atmosphere of 37 % CO, 9 % H_2O, 7 % CO_2, 46 % H_2, a_c = 163, $p(O_2) = 2.5*10^{-27}$bar at 600°C, 20 bar. No pits and no attack on edges up to 5693 h on VDM® Alloy 699 XA

Applications

VDM® Alloy 699 XA has a wide range of applications in the high-temperature field of chemical and petrochemical process industry.

Typical applications are:

- Reformers in the chemical and petrochemical industries
- Methanol and ammonia synthesis
- Hydrogen production
- Cooling of syngas during e-fuel production

Fabrication and Heat treatment

VDM® Alloy 699 XA can be easily formed both hot and cold and can also be machined.

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 result in damage during the heat treatment of VDM® Alloy 699 XA. 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. Heat treatment can basically be carried out in gas, oil or electrically heated equipment and also under air admission, protective gas or vacuum. Fuels for directly heated furnaces should have a sulfur content as low as possible. Natural gas with less than 0.1 % and heating oil with maximum 0.5 % sulfur are suitable if a slightly oxidizing furnace atmosphere is set. Reducing or changing conditions should be avoided. The workpiece should not be contacted directly by flames. Ensure that temperature control is precise.

Hot forming

VDM® Alloy 699 XA can be hot-worked at a temperature range of between 1,230 and 900 °C (2,246 and 1,652 °F) with subsequent rapid cooling down in air by using preferably air nozzles. The workpieces should be placed in the furnace, which has been already heated up to hot-working temperature. Once the temperature has equalized, the workpieces can be removed and worked within the stated temperature window. If the temperature is fallen below the lower limit, the workpiece must be re-heated. Heat treatment after hot forming is recommended in order to achieve optimal properties.

Cold forming

The workpieces should be in the solution-annealed condition for cold working. VDM® Alloy 699XA has a higher work hardening than austenitic stainless steels. This must be taken into consideration when choosing and designing forming equipment and forming processes. Intermediate annealing is necessary for major cold forming work. Solution annealing is recommended if a deformation of over 10 % is achieved. When bending and trimming metal sheets, an inner radius should be maintained that is more than three-times the thickness of the metal sheet in order to avoid damage.

Heat treatment

During each heat treatment, the material is to be inserted into the furnace, which has been already heated up to the annealing temperature. The cleanliness requirements listed under the "Heating" section must be fulfilled. VDM® Alloy 699 XA is usually used in the solution-annealed state, where optimal creep strength is given. VDM® Alloy 699 XA is solution-annealed at 1,100 °C to 1,180 °C (2,012 °F to 2156 °F) for maximum creep strength in order to specifically achieve a grain size of ≥ 75 µm (ASTM E 112 < 4.5). The retention time during annealing depends on the semi-finished product thickness and can be calculated as follows:

- For thicknesses d ≤ 10 mm (0.4 in), the retention time is t = d • 3 min/mm
- For thicknesses d = 10 to 20 mm (0.4-0.8 in), the retention time is t = 30 min + (d - 10 mm) • 2 min/mm
- For thicknesses d > 20 mm (0.8 in), the retention time is 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. If additional processes steps take place after the solution annealing, the cooling from the solution annealing temperature should take place e.g. in air or with compressed air (for metal sheets less than 3 mm (0.12 in) thickness). If solution annealing is the last processing step before use, cooling can be carried out more slowly in order to avoid warpage. 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 are delivered in the solution-annealed state with a descaled surface and develop a protective oxide layer in service.

Oxides from VDM® Alloy 699 XA and tempering colors in the area around welds have better bonding than in stainless steels. Grinding using extremely fine abrasive belts or grinding discs is recommended. Tempering colors caused by grinding (grinding burn) should be avoided. If pickling is to be carried out, the pickling times (as for all high-temperature materials) should be kept short because they can otherwise be subject to inter-crystalline attack. Furthermore, the temperature must be scrupulously observed. Before pickling in nitric-hydrofluoric acid mixtures, the oxide layers should be destroyed by abrasive blasting or fine grinding, or pre-treated in molten salt.

Stock removal machining
VDM® Alloy 699 XA is preferably processed in a solution-annealed condition. Since the alloy is prone to work-hardening, a low cutting speed should be selected with a feed speed that is not too high. The cutting tool should be engaged at all times. An adequate depth of cut is important in order to cut below the previously formed strain-hardened zone. The strong heat development during machining should be countered by a sufficient amount of cooling lubricant. Water-based emulsions such as those used for structural and stainless steels are very suitable for this purpose. Suitable cutter geometries, suitable cutter materials and cut values can be taken from the VDM Metals publication
Working and machining of austenitic special stainless steels and nickel alloys.

Welding information

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

Workplace
A separately located workplace, which is specifically separated from areas in which C (carbon) 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
Only stainless steel brushes may be used. Processing and treatment machines such as shears, punches or rollers must be fitted (felt, card-board, films) so that the workpiece surfaces cannot be damaged by the pressing in of iron particles through such equipment, as this can lead to corrosion.

Welding edge preparation
Welding edge preparation should preferably be carried out using mechanical methods such as lathing, milling or planning. 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 the arc
The arc may only be struck in the seam area, e.g. along the seam flanks or a shoe, and should not be carried out on the component surface. Areas where firing takes place are more susceptible to corrosion.

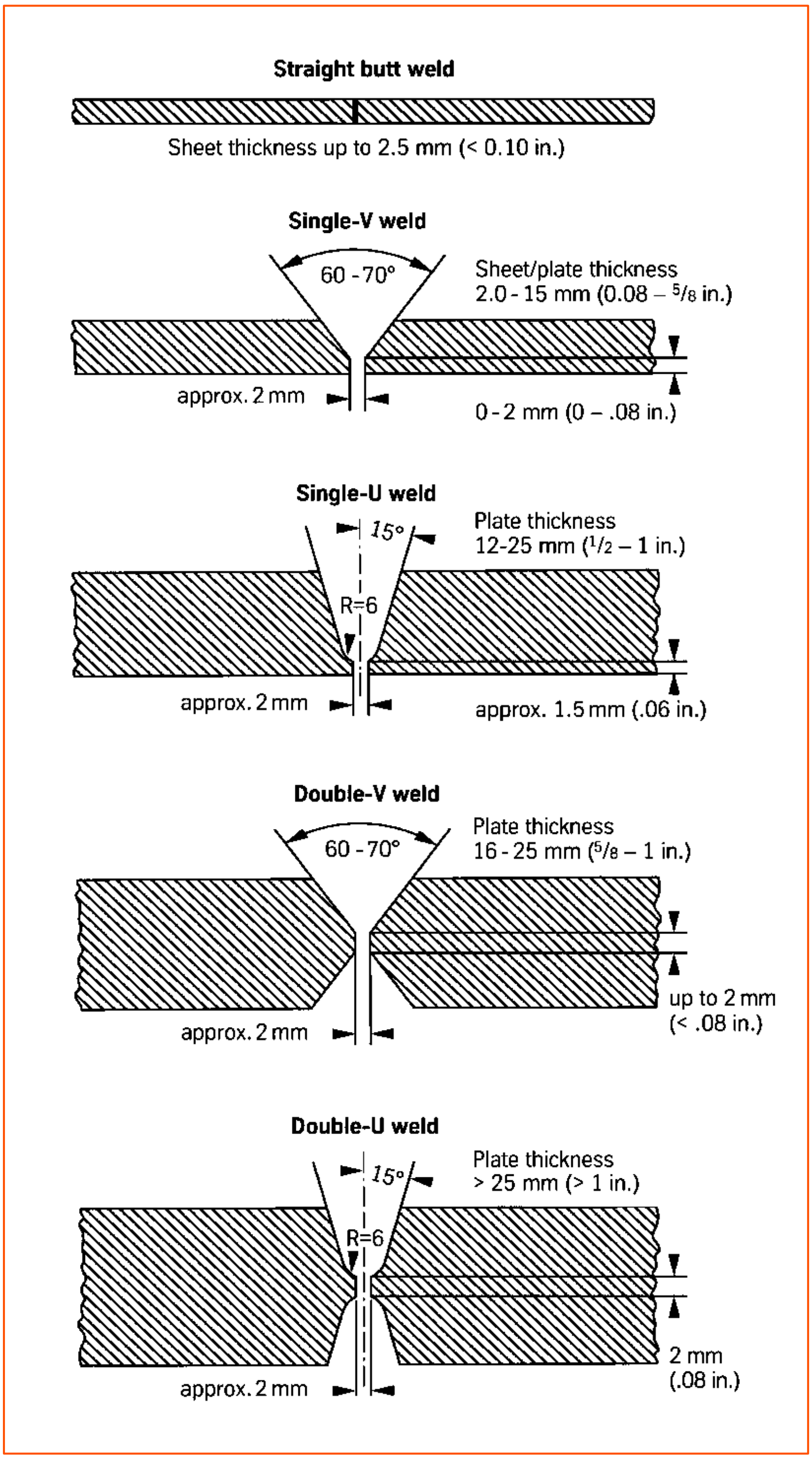

Figure 3 – Seam preparation for welding nickel alloys and special stainless steels

Included angle

Compared to C-steels, nickel alloys and special stainless steels have a lower heat conductivity and greater heat expansion. Larger root gaps (1 to 3 mm, 0.039 to 0.118 in) are required to take these properties into account. Due to the higher viscosity of the melt (compared to standard austenites) and the tendency to shrink, bevel angles from 60 to 70° – as shown in Figure 3 – have to be provided for butt welds.

Cleaning

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

Welding parameters and influences

It must be ensured that work is carried out using defined and relatively low heat input as shown in table 6 as an example. The stringer bead technique is recommended. The interpass temperature should not exceed 100 °C (212 °F). It is recommended to continuously monitor and check the essential welding parameters.

The nominal 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, amperes
v = welding speed, cm/minute

Welding filler
For fusion welding processes, the matching filler metal (same chemical composition as the base metal) is recommended:

VDM® FM 699 XA (N06699 (UNS), 2.4842 (Material no.)
ISO 18274: S Ni 6699 (NiCr29Al)
VdTÜV: Data sheet no. 19891 (S NiZ (NiCr30Al2)) *)
*) S NiZ (NiCr30Al2) was the provisional name of S Ni 6699 until its inclusion in ISO 18274

Post-treatment
After the welding has been successfully performed, 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. For the best results, especially in applications in atmospheres similar to syngas (carbon activity larger than one an low oxygen partial pressure), at temperatures between 400°C to 800°C, it is recommended to remove the heat tint thoroughly by grinding the weld and the heat affected zone using extremely fine abrasive belts or grinding discs. The information contained in the section entitled "Descaling and pickling" must be observed. Usually a preheating before welding is not required.

In order to achieve optimal creep strength of weld joint in the temperature range of about 600 to 650°C a PWHT at 1100°C for 40 minutes to 3 hours is required. For further information please contact VDM Metals.

Welding processes
Up to now, VDM® Alloy 699 XA has been welded by GTAW (TIG). For welding, VDM® Alloy 699 XA must be in the solution-annealed condition and be free from scale, grease and markings. When welding the root, care should be taken to achieve best quality root backing (pure Ar), so that the weld is free from oxides after welding the root. The shielding gas used for the GTAW should be an argon with a purity of at least 99.996 %. This gas should be used for all welding passes, i.e., for depositing the root, filling and top layers. Any heat tint should be removed preferably by brushing with a stainless steel wire brush while the weld metal is still hot.

Thickness	Welding technique	Filler material		Root pass[1]			Filling and top layer			Shielding gas	
(mm)		Diameter (mm)	Speed (m/min)	I in (A)	U in (V)	Welding speed (cm/min)	I in (A)	U in (V)	Welding speed (cm/min)	Type	Flow rate (l/min)
16	manual TIG	1.6 - 2.4	-	105 - 120	10 - 12	4 - 7	125 - 190	11 - 14	7 - 15	I1 (SG-A)	8 - 10
	autom. TIG[2]	1.0 - 1.2	1-2				205	15	12 - 14	I1 (SG-A)	8 - 12

[1] It must be ensured that there is sufficient root protection, for example using Ar 4.6, for all inert gas welding processes.
[2] The root pass should be welded manually (please see 'manual TIG' for parameters).
Figures are for guidance only and are intended to facilitate setting of the welding machines.

Table 5 – Exemplary welding parameters

Availability

VDM® Alloy 699 XA is available in the following semi-fabricated forms:

Sheet and Plate

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

Delivery condition	Thickness mm (in)	Width mm (in)	Length mm (in)	Piece weight kg (lb)
Cold rolled	1-7 (0.04-0.28)	≤ 2,500 (98.43)	≤ 12,500 (492.13)	
Hot rolled	3-50 (0.12-1.97)*	≤ 2,500 (98.43)	≤ 12,500 (492.13)	≤ 2.250 (3,858)

Sheets can be manufactured considering the minimum and maximum dimensions
* 2 mm (0.08 in) thickness on request

Strip

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

Thickness mm (in)	Width mm (in)	Coil - inside diameter mm			
0,025-0,15 (0.001-0.006)	4-230 (0.16-9	300	400	500	-
0,15-0,25 (0.006-0.01)	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

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

Rod and Bar

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

Dimensions*	Outer diameter mm (in)	Length mm (in)
General dimensions	6-600 (0.24-31.50)	1,500-12,000 (59.06-472.44)
Material specific dimensions	12-500 (0.31-15.75)	1,500-12,000 (59.06-472.44)

* Further dimensions on request.

Wire

Delivery condition: Drawn bright, weak 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)	5.5-18 (0.22-0.71)

Other shapes and dimensions available on request.

Technical publications

Clara Schlereth, Emma White, Maren Lepple, Benedikt Nowak, Heike Hattendorf, Mathias Galetz, Influence of the surface treatment on the metal dusting resistance of welds, Materials and Corrosion (2023), DOI: 10.1002/maco.202313954

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E. White, C. Schlereth1, M. Lepple2, B. Nowak3, H. Hattendorf3, M. Galetz1, Influence of the surface treatment on the metal dusting behavior of alloy 699 XA, Materials and Corrosion (2022), pp 191, DOI: 10.1002/maco.202213380

C. Schlereth, C. Oskay, H. Hattendorf, B. Nowak, M. C. Galetz, Influence of Al and Fe additions on metal dusting of NiCr alloys, Materials and Corrosion, 73 (2022), 1346-1358, DOI: 10.1002/maco.202112935

Tatiana Hentrich, Heike Hattendorf, Benedikt Nowak, Martin Wolf, Alejandra Lopez, VDM Alloy 699 XA considerations on weldability: heat treatments, mechanical properties and behavior under Metal Dusting Conditions, Nitrogen + Syngas Virtual Conference 2021, Conference, 01 – 03.03.2021.

Bingtao Li, Wei-Ting Chen, Brian Gleeson, Dr. Hattendorf, Effects of Minor Alloying Elements on Metal-Dusting Behavior of Bi-Based Alloys, All Summer 2020 Conference Digital Proceedings Papers CORROSION 2020, Paper No.: C2020-14657

Tatiana Hentrich, John Groth, Heike Hattendorf, Alejandra Lopez, VDM®Alloy 699 XA a new alloy for Syngas Applications under metal dusting conditions, 2019 Global Syngas Technologies Conference 2019, (October 27-29, 2019) Austin, Texas, USA.

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Hattendorf, H, Hermse, C.G.M., IJzerman, R.M. The influence of alloying elements on metal dusting behavior of nickel chromium alloys and their statistical correlation. Materials and Corrosion 70, pp 1385-1399. https://onlinelibrary.wiley.com/doi/10.1002/maco.201810593

Heike Hattendorf, Alejandra López, Jutta Klöwer, Alloy 699 XA: A new Alloy for Application in Petrochemical Industry under Metal Dusting Conditions, Corrosion/2018, Paper No.-11200 Phoenix (Phoenix: Nace, 2018)

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