VM12-SHC
Technical-Datasheet

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Technical datasheet of VM12-SHC

Introduction

VM12-SHC (Super High Corrosion resistant) is a 12Cr – 1.6Co - 1.5W – B ferritic steel developed by Vallourec Group. Potential applications include advanced power plants and HRSG (Heat Recovery Steam Generators) or replacement of X20CrMoV11-1 in current power plants. Its specific chemical composition provides a special performance in terms of creep resistance and steam corrosion.
VM12-SHC is suitable for applications with temperatures up to 620°C (1150°F). The seamless tubes in VM12-SHC are supplied by Vallourec's European continuous mandrel mills under normalized and tempered condition with a 12 mm (0.5 in.) wall thickness max.

Key features:

- 12Cr-Co ferritic steel with addition of W, Mo, V and Nb to improve creep strength
- Good creep properties, comparable with that of grade 91
- Excellent fabricability, (i.e. cold bending and weldability) similar to that of 9%Cr steels

Excellent oxidation resistance properties up to 650°C (1200°F)

Maximum design temperature is 620°C (1150°F) according to ASME Code Case 2781 and VdTÜV 560/2

Applicable international codes and standards

- ASME Code Case 2781: 12Cr – 1.5W – 1.6 Co – B Material
- VdTÜV Material Data Sheet 560/2 03.2009
- 1.4915, X12CrCoWMoVNb12-2-2, European Steel registration

Chemical composition

The chemical composition as specified by ASME Code Case 2781 or VdTÜV Material Data Sheet 560/2 is shown in Table 1.
It exhibits excellent resistance to high temperature steam oxidation due to the effects of chromium and silicon. The addition of Nb and V promotes the formation of fine MX and $M_{23}C_6$ type precipitates. The low level in carbon provides a good weldability. Through the addition of tungsten, cobalt and boron, a strengthening effect increases significantly the creep resistance.

Contents [%]		
	min.	max.
C	0.10	0.14
Si	0.40	0.60
Mn	0.15	0.45
P	-	0.02
S	-	0.01
Al	-	0.02
Cu	-	0.25
Cr	11.0	12.0
Ni	0.10	0.40
Mo	0.20	0.40
W	1.30	1.70
V	0.20	0.30
Nb	0.03	0.08
Co	1.40	1.80
B	0.003	0.006
N	0.030	0.070

Table 1 – Chemical composition of VM12-SHC

Heat treatment

The material shall be austenitized within the temperature range from 1040°C – 1080°C (1900°F – 1975°F) followed by air cooling and tempered within the range from 760°C – 800°C (1400°F – 1470°F). In addition, according to VdTÜV560/2, the soaking time for tempering should be min. 60 minutes followed by cooling in still air.

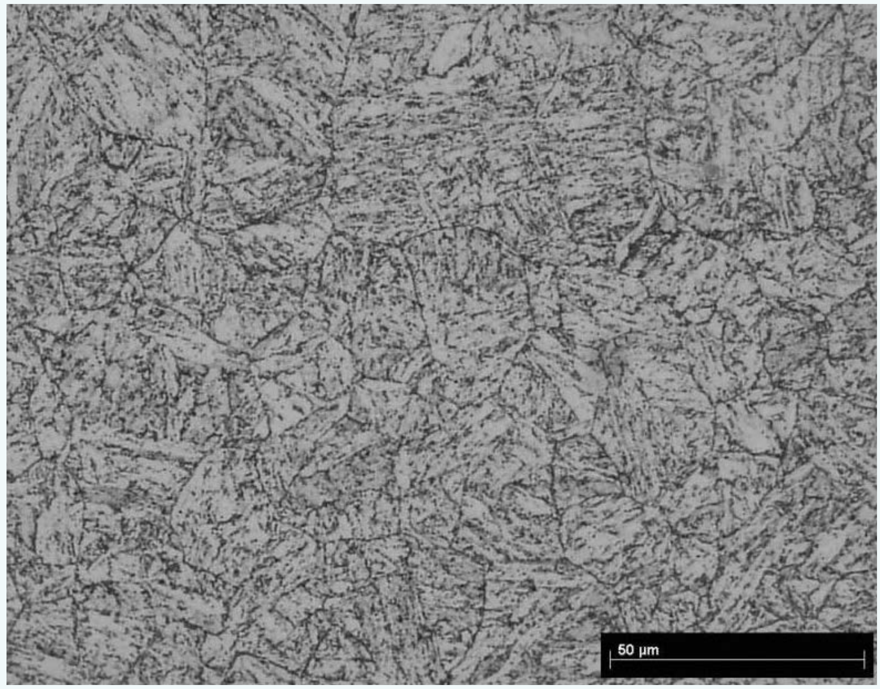
Austenitized range
1040°C – 1080°C
1900°F – 1975°F

Tempering range
760°C – 800°C
1400°F – 1470°F

Microstructure

Based on the aforementioned chemical composition and in combination with the described heat treatment (N+T) the obtained microstructure consists of fully tempered martensite.

Fully tempered
Martensit



> Figure 2 - Typical microstructure of VM12-SHC tube material after heat treatment (Tube OD 38 mm x WT 6.3mm).

Mechanical properties

Yield and tensile strength at room and elevated temperatures are located above the minimum values of T/P92 indicating that the tensile properties of both grades are very similar. The tensile properties at room temperature are shown in Table 2a in accordance with VdTÜV 560/2 and in Table 2b in accordance with ASME Code Case 2781.

Specimen orientation	R_{eH} [MPa]	R_m [MPa]	A [%]
longitudinal	≥ 450	620 - 850	≥ 19
transverse			≥ 17

› Table 2a – Tensile properties of VM12-SHC in VdTÜV 560/2

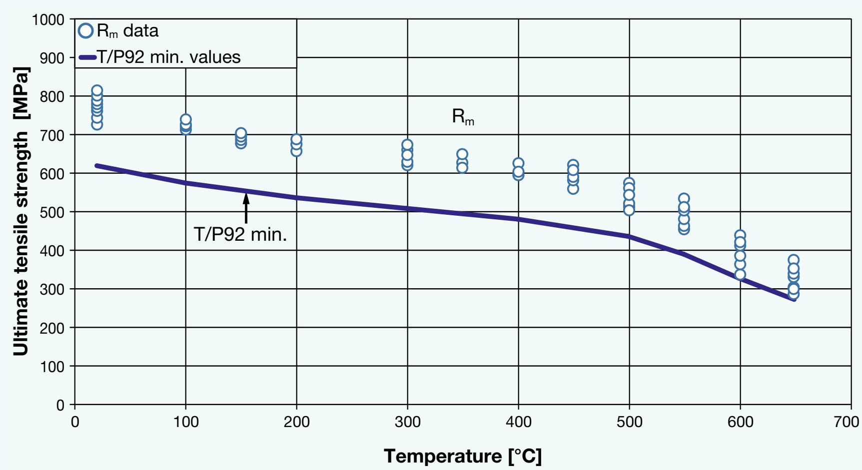
	ksi	[MPa]	% [note (1)]
Tensile strength, min.	89.9	620	
Yield strength, min	65.3	450	
Elongation in 2 in. min.			19

› Table 2b – Tensile properties of VM12-SHC in ASME Code Case 2781

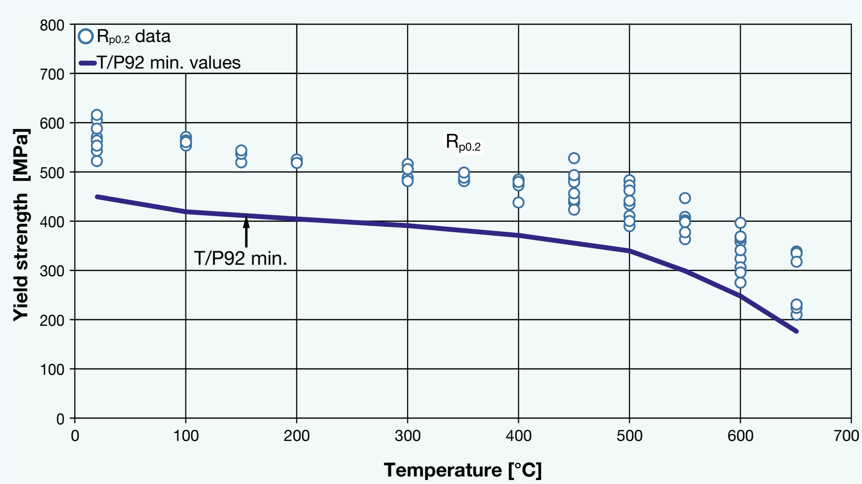
NOTE: For longitudinal strip tests, a deduction from the basic values of 1.00% for each 1/32 in. (0.8 mm) decrease in wall thickness below 5/16 in. (7.8mm) shall be made. The computed values are given in the ASME Code Case 2781.

Tensile properties at elevated temperatures lie above the minimum values of T/P92 (Figures 3 and 4)

Tensile properties above
minimum T/P92
values



› Figure 3 – Ultimate Tensile Strength



› Figure 4 – Yield Strength

According to ASME Code Case 2781, the material in the final tempered condition shall not exceed a Brinell Hardness Number of 250 HBW (HRC 25).

According to VdTÜV 560/2, the steel has a hardness of 185-265 HV.

Creep properties and allowable stresses

VM12-SHC has been extensively characterized regarding creep properties. Creep tests have been performed in the temperature range between 525°C and 700°C at different stresses with test duration longer than 45,000h and cumulated more than 2.7 million hours of testing time. Figures 5, 6 and 7 illustrate the creep results performed on tubes at 600°C, 625°C and 650°C (1110°F, 1160°F and 1200°F).

Specimen orientation	Specimen type	Test temperature	Impact energy KV[1)] [J]
longitudinal	Charpy V-notch	Room temperature	≥ 40
transverse			≥ 27

[1)] Average value of 3 specimens. Only one individual value may be below the minimum average value, proviced it is not less than 70% of that value.

Table 4 – Impact energy in accordance with VdTÜV 560/2

The maximum allowable stress values for the design according ASME rules shall be those given in Table 5a or Table 5b.

For Metal Temperature Not Exceeding, °C	Tubes
-30 to 40	177
100	177
200	167
300	161
400	156
450	149
475	144
500	138
525	130
550	121
575	97
600	71
625	47 [2]

For Metal Temperature Not Exceeding, °F	Tubes
-20 to 100	25.7
200	25.7
300	25.3
400	24.2
500	23.6
600	23.3
650	23.2
700	23.0
750	22.7
800	22.2
850	21.5
900	20.7
950	19.5
1000	18.2
1050	15.5
1100	11.3
1150	7.3

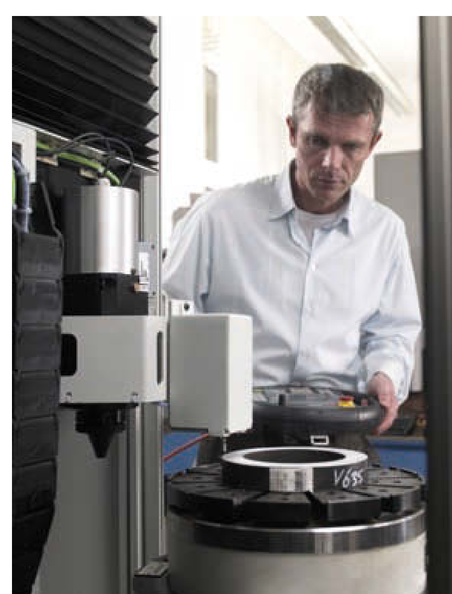
> Tables 5a and 5b: Maximum Allowable Stress Values, MPa (5a) and ksi (5b) [1]

[1] Values shown in italics are obtained from time-dependent properties.
[2] The maximum use temperature shall be 621° C. Datum for 625° C temperature is provided for interpolation purposes.

Hardness
185 – 265 HV

Creep test duration
> 45,000h

Cumulated testing time
> 2.7
million hours



The table 6 contains reference data for the creep rupture strength of the base material according to VdTÜV 560/2. Based on available documentation of long-time tests, it can be assumed that the lower limit of the scatter band is about 20% lower at the relevant temperatures than the mean value shown.

Available documentation of
long-time tests

Temperature [°C]	Creep ruture strength for	
	10,000 h [MPa]	100,000 h [MPa]
550	217	162
560	202	145
570	187	130
580	172	115
590	158	102
600	144	90
610	130	78
620	116	68

> Table 6 - Long-time high-temperature strength values according to VdTÜV 560/2

Physical properties

The main physical properties have been measured and reported in Table 7a or 7b, in accordance with ASME Code Case 2781.

Temperature (°C)	20	100	200	300	400	500	600	650
Modulus of Elasticity, (Tension, 10^3 MPa)	220	215	208	200	190	179	166	158
Thermal Conductivity, (W/(m-°C)	24.2	25.2	26.2	27.1	27.9	28.5	29.1	29.3
Mean CTE*, (10^{-6} mm/mm/°C)		10.5	10.9	11.2	11.5	11.8	12.1	12.2

> Table 7a - Physical Properties

* Mean CTE values are those from 20°C to indicated temperature

Temperature (°C)	68	200	400	600	800	1000	1150
Modulus of Elasticity, (Tension, 10^3 ksi)	31.91	31.25	30.12	28.78	27.13	25.25	23.59
Thermal Conductivity, (Btu/ft-hr-°F)	13.0	14.3	15.0	15.8	16.2	16.6	16.8
Mean CTE*, (10^{-6} in/in/°F)		5.84	6.06	6.25	6.44	6.67	6.79

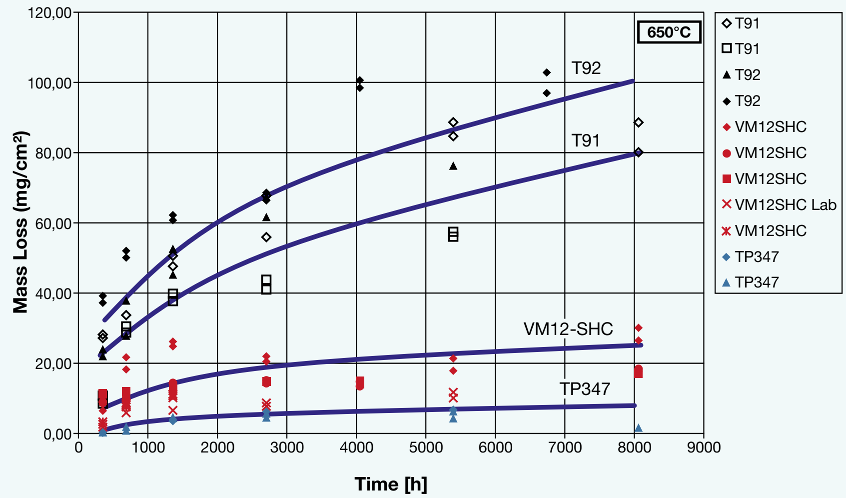
> Table 7b - Physical Properties

* Mean CTE values are those from 68°F to indicated temperature

Steam oxidation resistance

The oxidation experiments were performed at 600°C and 650°C in pure water vapor (at Ecole des Mines, Douai, France). The test results at 650°C are presented in Figure 8. For comparison the T91, T92 and TP347FG material was tested as well. The steam oxidation resistance of VM12-SHC is comparable with that of the austenitic steel TP-347FG and significantly better than that of T91 and T92.

Steam oxidation resistance
comparable
to TP347FG



› Figure 8 - Oxidation behavior of VM12-SHC in steam at 650°C in comparison to T/P91, T/P92 and the austenitic grade TP347FG.

Cold bending on VM12-SHC tubes

Cold bending experiments were performed on tube material. No cracking was observed. VM12-SHC has the same behavior than that of T92. All requirements with respect to microstructure and hardness in as bent condition and after stress relief treatment are met. Creep tests on samples from bends showed similar rupture times to those obtained on mother tube: no softening or creep drop could be observed after stress relief treatment. No recrystallisation was observed: the metallurgical structure is very stable.

Cold bending
no cracking

Stress relief treatment
no softening

Metallurgical structure
very stable

Recommendations in the VdTÜV 560/2

Cold bent tubes with outside diameters $\leq$ 76.1 mm and a ratio for bending radius-to-outside diameter $R_m/D_a \geq 1.8$ require no heat treatment. If $R_m/D_a < 1.8$, then a stress relieving must be performed. It consists in a heat treatment between 740 and 770°C, soaking time: 2 min/mm thickness min. 60 minutes, cooling in still air. The soaking time begins when the specified temperature has been attained through the cross section.

Cold bent tubes with outside diameters > 76.1 mm and a bending radius-to-outside diameter ratio $R_m/D_a \geq 3$ require no heat treatment. If $R_m/D_a < 3$, a renewed heat treatment (austenizing followed by tempering) as described in page 3 is required.

This also applies to necking and expansion operations with comparable reduction ratios.
All other forming operations with reduction ratios > 5% must be followed by renewed heat treatment as described here above.

Recommendations in the ASME Code Case 2781

All cold formed material which is designed for service at a nominal temperature of 480°C (900°F) or higher shall be heat treated in accordance with the following rules. Cold bending or forming is defined as any method that produces strain in the material and is performed at a temperature below 650°C (1200°F). The calculations of cold strains shall be made as described in ASME Section I, PG-19.

(1) For tubes of diameter smaller or equal to 76.1 mm (3 in.) with greater than 28% strain, the cold formed area, including the transition to the unstrained portion, shall be stress relieved at a temperature between 740°C and 780°C (1365°F and 1435°F), with a soaking time of 1 hour, followed by cooling in air.

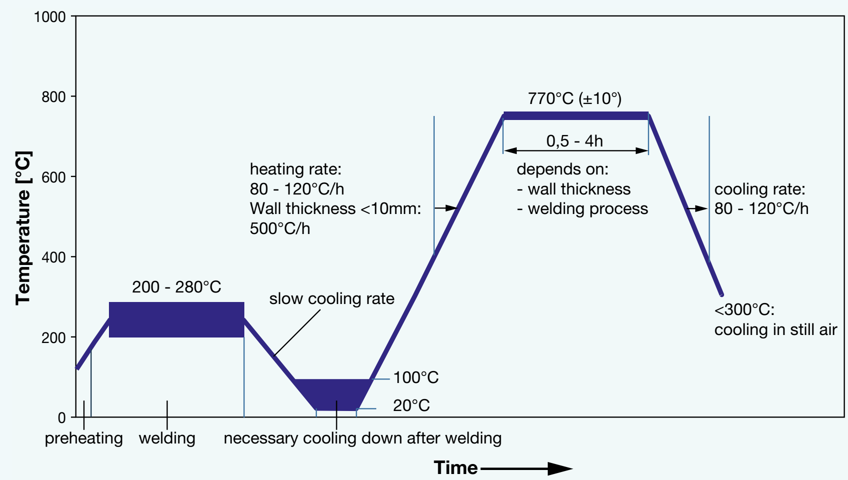
(2) For all cold swages, flares and upsets regardless of the dimension and the amount of cold reduction, and for tubes of diameter greater than 76.1 mm (3 in.) with greater than 17% strain, the material shall be reaustenitized and tempered in accordance with heat treatment described in page 3. This heat treatment shall not be performed locally. The material shall be either heat treated in its entirety, or the cold strained area (including the transition) shall be cut away from the balance of the tube or component, and heat treated separately or replaced.

(3) In all other cases, heat treatment is neither required nor prohibited.

Welding

Welding consumables and welding procedure specifications for VM12-SHC are qualified and available. Schematic diagram of temperature cycle during welding of VM12-SHC and subsequent PWHT is described in Figure 9. After welding and before a post-weld heat treatment, cooling below 100°C is required. Heat treatment is mandatory after welding. No susceptibility of stress relief cracking was observed.

Welding consumables
and welding procedures
qualified + available



› Figure 9 - Typical heating cycle for welding VM12-SHC
(Graphic: voestalpine Böhler Welding)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