Boiler Grade DMV 310 N

SALZGITTER
MANNESMANN
STAINLESS TUBES

A Member of the Salzgitter Group

Content

1 Introduction

Headquarters Mülheim an der Ruhr, Germany

1.1 Salzgitter Mannesmann Stainless Tubes

Salzgitter Mannesmann Stainless Tubes is one of the leading manufacturers of seamless stainless steel and nickel alloy tubes and pipes. Our company has one of the largest product portfolios in this sector.

Our top quality products and efficient service contribute to the long-term success of our customers. Our top priority is to establish and maintain positive long-term relationships with our business partners.

In order to support you in the stockist and project business, with good quality, innovative materials and modern production technologies, our experts are constantly working to keep up with the latest trends.

As a company operating successfully on an international level, we unite many nationalities and cultures under one banner. Our network collaborates closely in all aspects of procurement, sales, production and logistics.

Since our foundation as a joint venture, we hold our position in the top league of companies in this sector.

We are a member of the powerful Salzgitter Group and our stainless steel and nickel base products are an important addition to the Group's overall product range. Thanks to our impressive product portfolio, we can open up attractive growth prospects.

1.2 DMV 310 N

Our tubes and pipes are primarily used for boilers in thermal power plants and the energy sector. The trend is towards higher steam temperatures to increase the efficiency of power plants on the one hand and the use of high chlorine and sulphur containing coal on the other hand. Conventional 18-8 stainless steels such as grades 304 and 347 do not show sufficient corrosion resistance in these cases. The higher Cr containing stainless steels of type 310 (25Cr-20Ni) exhibit a higher corrosion resistance. This type has been considered as a candidate material in cases where higher corrosion resistance is required and the higher material costs are acceptable. However, the creep rupture strength of conventional 310 stainless steel is rather low. Thus, these steels cannot be used to produce superheater tubes utilised above 600 °C (1110 °F). To find a remedy, composite tubes have been produced clad with type 310 stainless steel as the fire-side component on a core steel tube which provides satisfactory creep resistance.

With DMV 310 N, the disadvantage of low strength and creep resistance is overcome, while retaining the high corrosion resistance. The addition of niobium and nitrogen results in increased elevated temperature strength and creep resistance. The effects of solid solution strengthening by nitrogen together with the precipitation hardening by fine and stable NbCrN are used. 310 stainless steels can be prone to the formation of coarse secondary phases such as sigma phase and Cr_2N resulting in an embrittlement of the material (reduced toughness). An optimisation of the composition (mainly nickel, niobium and nitrogen content) was necessary to increase the microstructural stability. Therefore the alloy composition is designed to find the optimum balance between the various properties. In this way, tubing in DMV 310 N is now suitable for use in superheater boilers above 600 °C (1110 °F).

1.3 Trend

Efficiency is a major performance criterion for power plants and boilers. Increasing efficiency essentially results in a reduction of the fuel consumption and thus CO2 emissions, which is a big challenge at the present time. Higher efficiency of such equipment is reached by higher steam temperatures and pressures. Target service conditions are currently steam temperatures above 600 °C or 1110 °F and pressures of more than 300 bar or 4,350 psi. The materials must withstand these conditions throughout the whole service life of the component. This results in higher demands on creep resistance, elevated temperature strength and high temperature corrosion resistance. The use of coal with a high chlorine and sulphur content further increases the need for fire-side corrosion resistance. These challenges are met by DMV 310 N, in which the high corrosion resistance of type 310 materials is combined with increased high temperature strength and creep resistance.

In future, steel development must continue to follow the new demands and challenges of boiler applications. It is widely expected that new power plants will run at even higher temperatures and pressures. Nickel based alloys in particular will be able to meet future requirements, such as DMV 617 (for design temperatures > 700 °C). However, these alloys have high nickel and chromium content and are thus more expensive.

1.4 Specifications (Standards)

DMV 310 N fulfils the requirements according to the following specifications:

- 1.4952 (X6CrNiNbN 25 20), according to EN 10216-5, European Standard
- TP 310HCbN (25Cr-20Ni-Nb-N) according to ASME SA-213, US Standard
- ASME Code Case 2115-1 (02.2000), United States
- VdTÜV material data sheet 546 (03.2007), Federal Republic of Germany

1.5 Available Sizes

DMV 310 N austenitic stainless steel is used to manufacture seamless austenitic reheater and superheater boiler tubes. This grade is suitable for all commonly used austenitic reheater and superheater boiler tube sizes in the most advanced coal fired power stations with steam temperatures up to 620 °C (1150 °F) and supercritical or ultra supercritical boiler design.

VdTÜV material data sheet 546 (03.2007) allows a maximum outer diameter of 65 mm and a maximum wall thickness of 12.5 mm. The standard size range according to EN-ISO 1127 as well as other sizes are also available upon request.

1.6 Special Features

- DMV 310 N is an optimised austenitic stainless steel of type 310, suitable for use as **tubes in severe conditions** of modern boilers (e.g. ultra super critical boilers) with an appropriate combination of high corrosion resistance and high elevated temperature strength.
- **Production route of DMV 310 N:** The material is first subjected to a hot forming process (hot extrusion). Subsequently, cold finishing is carried out on the material, followed by solution annealing at a temperature between 1180 °C and 1270 °C (2155 °F and 2320 °F) according to VdTÜV data sheet 546 (03.2007).
- A high fire-side hot **corrosion resistance** and steam-side oxidation resistance is ensured by a high chromium content of 25 %.
- Satisfactory **elevated temperature strength** and **creep resistance** is achieved by the controlled additions of nitrogen and niobium: solid solution strengthening and precipitation hardening are employed.

- The optimised composition of DMV 310 N results in a **microstructural stability** reducing the tendency towards formation of coarse sigma and Cr_2N phase, and thus reducing embrittlement of the material.

2 Material Properties

2.1 Microstructure

The material DMV 310 N is a type 310 austenitic stainless steel with high corrosion resistance. Improvements in the elevated temperature strength and creep resistance compared to the conventional 310 types are mainly achieved by a balanced addition of niobium and nitrogen. In particular the nitrogen content is increased compared to the 310 type austenitic steels as well as compared to other boiler tube grades such as DMV 347 HFG and DMV 304 HCu. To increase the strength of the material, primarily the effect of solid solution-strengthening by nitrogen is used. The creep resistance is further increased during service by the fine precipitation of carbonitrides, Z phase (complex nitride) and $M_{23}C_6$ carbides. Nevertheless, a high amount of nitrogen remains in solution in the austenitic matrix [1].

The production of boiler tubes is divided into three main processing steps. A first thermal treatment is performed during the hot extrusion of the material. This is followed by cold deformation to produce the final dimensions of the tube (cold pilgering or cold drawing). A final heat treatment completes the production route. During this solution treatment, the precipitates are mainly dissolved in the austenitic matrix. A high solution rate is necessary to achieve good creep properties. However, a certain amount of precipitates remains, restricting the grain coarsening by pinning the grain boundaries. These two aims are achieved by using a thermal treatment which is optimised in temperature and time. The microstructure of DMV 310 N in as-delivered condition is shown in Figure 1.

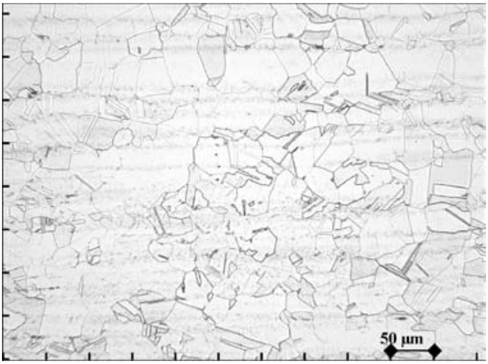

Figure 1: Microstructure of DMV 310 N in solution-annealed condition.

In the solution-annealed condition the dissolved nitrogen increases the tensile strength at room temperature and elevated temperatures by the solid solution-strengthening effect. Under creep conditions in service, precipitation of different phases begins.

As well as the well-known phases such as niobium carbonitrides, other more complex chromium containing nitrides such as the Z phase (NbCrN) are formed [2]. Since niobium is mainly tied to nitrogen, enough carbon is left in solution to form $M_{23}C_6$ carbides. Although the amount of nitrides and carbonitrides increases with time and temperature, most of the nitrogen remains in solution.

The intragranular NbCrN precipitates are very fine and stable even after long aging times contributing to the creep resistance by precipitation hardening [3, 4]. On the other hand, $M_{23}C_6$ also mainly formed intergranularly could lead to grain boundary chromium depletion and hence slightly enhances intergranular corrosion. This is accepted due to the advantage of higher strength, making it possible to use DMV 310 N as a monobloc tubing material without the need for cladding or coextrusion with a more creep resistant steel alloy.

Grade 310 stainless steels are prone to the unwanted formation of coarse sigma, Cr_2N or Pi (mixed nitride) phases. At comparably low levels of nitrogen and nickel (0.19 % N and 17 % Ni) precipitation of Cr-rich sigma phase occurs. Conversely, if the nitrogen and nickel contents are high (0.29 % N and 23 % Ni) the precipitation of Cr_2N and Pi phases is detected, deteriorating impact strength [3]. Other alloying elements also influence the formation of these deleterious phases. For this reason, optimisation of the alloy composition is performed to reduce the amount of these coarse secondary phases and hence to minimise embrittlement of the material. The microstructure of DMV 310 N after creep rupture test at 750 °C and 105 MPa is shown in Figure 2. The creep damage in form of microcracks orientated perpendicular to the stress direction is typical. Precipitation of nitrides has taken place inside the grains and at grain boundaries.

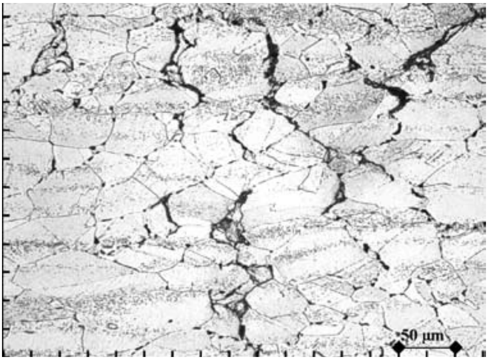

Figure 2: Microstructure of DMV 310 N after failure in creep rupture test (750 °C, 105 MPa, 649 h).

2.2 Material properties according to ASME

The material meets the requirements of TP 310 HCbN as specified in ASME SA-213. The required material properties are further described in the ASME Code Case 2115-1: 25Cr-20Ni-Nb-N.

2.2.1 Chemical composition

The requirements with regard to the chemical composition given in ASME SA-213 and the ASME Code Case 2115-1 are summarised in Table 1. A solution treatment at a temperature of at least 2,000 °F (1,100 °C) is performed before delivery.

[wt-%]	C	Si	Mn	P	S	Cr	Ni	Nb	N
min.	0.04	-	-	-	-	24.0	17.0	0.20	0.15
max.	0.10	0.75	2.00	0.03	0.03	26.0	23.0	0.60	0.35

Table 1: Chemical composition of DMV 310 N.

	ksi	MPa [1]	%
Minimum yield strength	43	295	-
Minimum tensile strength	95	655	-
Minimum elongation in 2 inch	-	-	30

[1] calculated values

Table 2: Mechanical properties at RT in solution-annealed condition according to ASME SA-213, Code Case 2115-1.

2.2.2 Mechanical properties

Tensile properties at room temperature (RT) in the solution-annealed condition according to ASME SA-213 and the ASME Code Case 2115-1 are given in Table 2. Additionally, the hardness shall not exceed 256 HB (100 HRB).

In the ASME Code Case 2115-1, the maximum allowable stress values at different temperatures are given (see Table 3, Figure 3). They are based on factor of 3.5 on tensile strength, where applicable. In the second column higher values are given for cases in which slightly greater deformation (1 %) is acceptable. These values exceed 66.67 %, but do not exceed 90 % of the yield strength at elevated temperature. The use of these stress values may result in dimensional changes due to permanent strain. For this reason, these stress values are not recommended for the flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

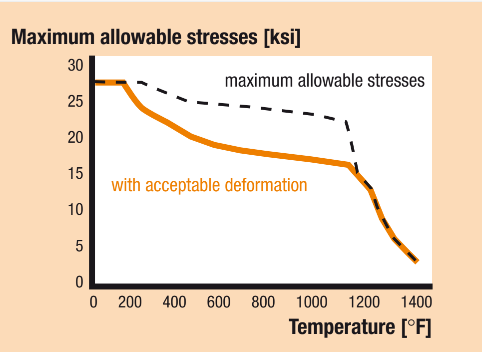

Figure 3: Maximum allowable stresses according to ASME Code Case 2115-1.

Temperature		Maximum allowable stresses		Maximum allowable stresses [2]	
°F	°C [1]	ksi	MPa [1]	ksi	MPa [1]
-20 to 100	-29 to 38	27.1	186.8	27.1	186.8
200	93	24.0	165.5	26.9	185.5
300	149	21.7	149.6	25.4	175.1
400	204	20.2	139.3	24.6	169.6
500	260	19.2	132.4	24.2	166.9
600	316	18.5	127.6	24.0	165.5
650	343	18.3	126.2	23.9	164.8
700	371	18.1	124.8	23.8	164.1
750	399	17.8	122.7	23.7	163.4
800	427	17.6	121.3	23.6	162.7
850	454	17.4	120.0	23.4	161.3
900	482	17.1	117.9	23.1	159.3
950	510	16.9	116.5	22.8	157.2
1000	538	16.6	114.5	22.4	154.4
1050	566	16.3	112.4	22.0	151.7
1100	593	16.1	111.0	16.1	111.0
1150	621	13.6	93.8	13.6	93.8
1200	649	10.1	69.6	10.0	69.6
1250	677	7.6	52.4	7.6	52.4
1300	704	5.7	39.3	5.7	39.3
1350	732	4.3	29.6	4.3	29.6

[1] calculated values

[2] slightly greater deformation acceptable

Table 3: Maximum allowable stresses at elevated temperatures according to ASME Code Case 2115-1, US customary units and SI metric units.

2.3 Material properties according to VdTÜV

In the following, material properties as given in the VdTÜV material data sheet 546 (03.2007) are summarised.

2.3.1 Chemical composition

The requirements with regard to chemical composition are given in Table 4. The composition given in the VdTÜV material data sheet for the heat analysis is nearly the same as that given in ASME SA-213 and the ASME Code Case 2115-1. However, no minimum carbon content, a higher silicon content and a larger range for the chromium content is given in the VdTÜV material data sheet. According to standard practice in Europe, the requirements for the product analysis are slightly extended. Solution annealing of the finished tubes is carried out at a temperature between 1180 and 1270 °C (2155 to 2320 °F).

2.3.2 Tensile properties

Tensile properties at room temperature are given in Table 5. The values for proof strength are minimum values and are valid irrespective of location and position of the sample.

	[wt-%]	C	Si	Mn	P	S	Cr	Ni	Nb	N
Cast analysis	**min.**	-	-	-	-	-	23.0	17.0	0.20	0.15
	max.	0.10	1.50	2.00	0.030	0.030	27.0	23.0	0.60	0.35
Product analysis	**min.**	-	-	-	-	-	22.8	16.85	0.15	0.14
	max.	0.11	1.55	2.04	0.035	0.035	27.2	23.20	0.65	0.36

Table 4: Chemical composition of DMV 310 N.

	MPa	ksi [1]	%
0.2 % proof strength, min.	295	42.8	-
1 % proof strength, min.	325	47.1	-
Tensile strength	655 - 900	95.0 - 131	-
Elongation at fracture	-	-	30

[1] calculated values

Table 5: Tensile properties at room temperature according to the VdTÜV material data sheet 546 (03.2007).

Tensile properties at elevated temperatures are presented in Table 6 and Figure 4. The 0.2 % and 1 % proof strength and the tensile strength are summarised. The samples are taken in longitudinal direction. The proof strength values are requirements, whereas the data for tensile strength at elevated temperature are only guidelines.

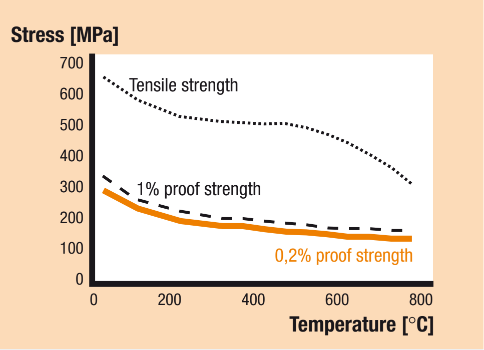

Figure 4: Minimum proof strength and tensile strength at elevated temperatures according to the VdTÜV material data sheet 546 (03.2007).

Temperature		**0.2 % proof strength**		**1 % proof strength**		**Tensile strength**	
°C	**°F [1]**	**MPa**	**ksi [1]**	**MPa**	**ksi [1]**	**MPa**	**ksi [1]**
100	212	240	34.8	265	38.4	590	85.6
200	392	205	29.7	230	33.4	540	78.3
300	572	190	27.6	210	30.5	525	76.1
350	662	190	27.6	210	30.5	525	76.1
400	752	180	26.1	200	29.0	520	75.4
450	842	175	25.4	195	28.3	520	75.4
500	932	170	24.7	190	27.6	510	74.0
550	1022	165	23.9	185	26.8	490	71.1
600	1112	160	23.2	180	26.1	465	67.4
650	1202	160	23.2	180	26.1	436	63.1
700	1292	155	22.5	175	25.4	395	57.3
750	1382	155	22.5	175	25.4	345	50.0

[1] calculated values

Table 6: Minimum proof strength and tensile strength at elevated temperatures according to the VdTÜV material data sheet 546 (03.2007).

2.3.3 Creep rupture strength

The creep rupture strength values for 10,000 h and 100,000 h are summarised in Table 7. These are long term values, based on evaluations of available test results to date. They are average values from existing scatter bands. These datasets are checked and may be revised from time to time in the VdTÜV material data sheet. It can be assumed that the lower limit of the scatter band is about 20 % lower than the given average.

In Figure 5, the average values of the creep strength for 10,000 and 100,000 h are given together with the minimum values of the 0.2 % proof strength of DMV 310 N showing the typical intersection of these values.

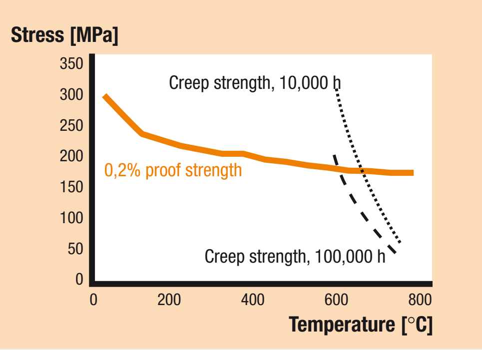

Figure 5: Creep strength for 10,000 and 100,000 h in comparison to the 0.2 % proof strength at elevated temperatures.

Temperature		**10,000 h**		**100,000 h**	
°C	**°F [1]**	**MPa**	**ksi [1]**	**MPa**	**ksi [1]**
600	1112	284	41.2	184	26.7
610	1130	260	37.7	170	27.7
620	1148	238	34.5	154	22.3
630	1166	212	30.7	140	20.3
640	1184	190	27.6	126	18.3
650	1202	171	24.8	114	16.5
660	1220	154	22.3	102	14.8
670	1238	142	20.6	90	13.1
680	1256	130	18.9	82	11.9
690	1274	118	17.1	73	10.6
700	1292	108	17.7	66	9.6
710	1310	98	14.2	59	8.6
720	1328	89	12.9	53	7.7
730	1346	79	11.5	48	7.0
740	1364	71	10.3	43	6.2
750	1382	64	9.3	39	5.7

[1] calculated values

Table 7: Average creep strength values for 10,000 h and 100,000 h according to the VdTÜV material data sheet 546 (03.2007).

2.3.4 Impact resistance

According to the VdTÜV material data sheet 546 (03.2007), the average impact energy in longitudinal direction should be at least 85 J at room temperature. This value is the average of 3 specimens. Only one of the 3 results is permitted to fall below the required level, by a maximum of 30 %.

Samples aged in the temperature range of 600 to 800 °C for up to 10,000 h did not become brittle, as the formation of coarse secondary phases such as sigma or Cr_2N phase was avoided. The precipitation of these phases leads to a reduction in impact strength.

In the VdTÜV material data sheet 546 (03.2007) it is stated that decreased impact value should be considered during downtimes, hydrostatic pressure tests etc.

2.3.5 Physical properties

In Table 8 and Figure 6, the dynamic modulus of elasticity is given. The summarised values are guidelines.

Temperature		Modulus of elasticity	
°C	°F 1)	10^3 MPa	10^3 ksi 1)
20	68	193	28.0
100	212	191	27.7
200	392	184	26.7
300	572	175	25.4
400	752	167	24.2
500	932	161	23.3
600	1112	150	21.8
700	1292	144	20.9
750	1382	141	20.5

1) calculated values

Table 8: Modulus of elasticity according to the VdTÜV material data sheet 546 (03.2007).

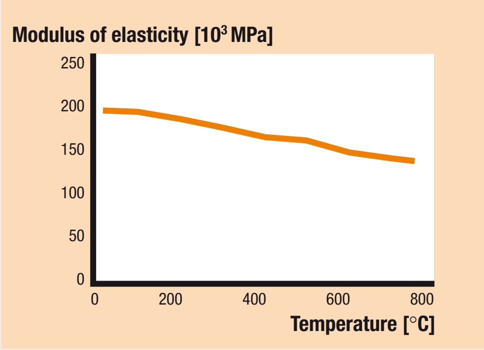

Figure 6: Modulus of elasticity according to the VdTÜV material data sheet 546 (03.2007).

2 Material Properties

The coefficient of thermal expansion is given in Table 9 and Figure 7. The reference temperature is 20 °C. The given values are guidelines.

Temperature: between 20 °C and …		**Coefficient of thermal expansion**	
°C	**°F 1)**	**10^{-6} / K**	**10^{-6} / °F 1)**
100	212	13.4	7.4
200	392	15.6	8.7
300	572	16.0	8.9
400	752	17.0	9.5
500	932	17.2	9.5
600	1112	17.5	9.7
700	1292	17.9	9.9
750	1382	18.0	10.0

1) calculated values

Table 9: Coefficient of thermal expansion (reference temperature 20 °C (68 °F)) according to the VdTÜV material data sheet 546 (03.2007).

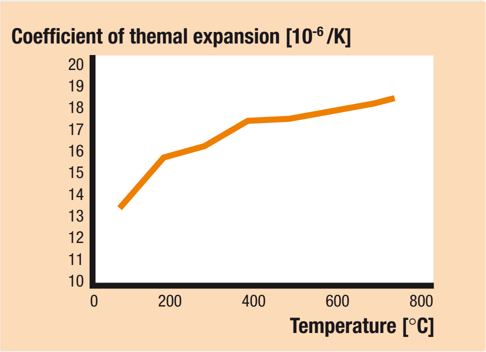

Figure 7: Coefficient of thermal expansion (reference temperature 20 °C (68 °F)) according to the VdTÜV material data sheet 546 (03.2007).

In Table 10 and Figure 8, the values of the thermal conductivity are summarised. Here again, the given values are guidelines.

Temperature		**Thermal conductivity**	
°C	**°F 1)**	**W / (m·K)**	**Btu / (ft·h·°F) 1)**
20	68	12.1	7.0
100	212	13.4	7.7
200	392	15.1	8.7
300	572	16.7	9.7
400	752	18.2	10.5
500	932	19.8	11.4
600	1112	21.2	12.3
700	1292	24.0	13.9
750	1382	24.4	14.1

1) calculated values

Table 10: Thermal conductivity according to the VdTÜV material data sheet 546 (03.2007).

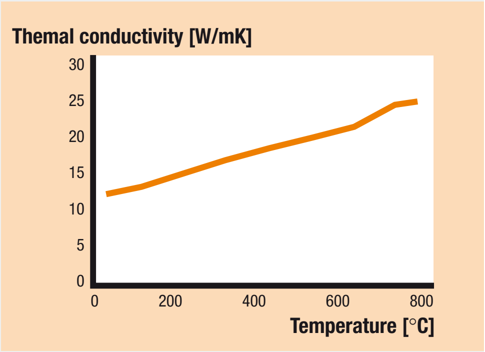

Figure 8: Thermal conductivity according to the VdTÜV material data sheet 546 (03.2007).

2.4 High temperature properties – Mechanism

The efficiency of conventional steam power plants depends to a large degree on the steam temperature and the pressure. Steam temperature has increased by about 60 °C (110 °F) in the last 30 years and a further increase of up to 100 °C (180 °F) is expected in the next 30 years. The major limiting factor for further increases in steam temperature is the resistance of the utilised material to corrosion and creep. The need for higher corrosion resistance due to higher steam temperatures as well as high chlorine and sulphur containing coal (fire-side atmosphere) is met by the higher chromium content of type 310 austenitic stainless steels. The high temperature strength and creep resistance of these steels is improved in DMV 310 N by optimising the alloy composition. In particular the increase in nitrogen content has improved the creep resistance, especially in the temperature range between 600 and 670 °C (1110 and 1240 °F). Thus, the use of this type 310 austenitic stainless steel is possible for boiler tubes, avoiding the higher production effort for cladding or coextrusion of different materials.

2.4.1 High temperature and creep rupture strength

An improvement of mechanical properties, especially high temperature strength and creep strength, can be achieved by solid solution strengthening or precipitation hardening effect. Through the addition of nitrogen, both effects are used in the DMV 310 N stainless steel. In the solution-annealed condition only a small amount of precipitates is present in the material. The nitrogen is mainly dissolved in the austenitic matrix material, and room temperature and elevated temperature strength is enhanced by solid solution strengthening. It is considered that nitrogen is more soluble than carbon, with a maximum solubility at chromium contents of around 25 %. Furthermore, the effect of solid solution strengthening is greater for nitrogen than for carbon, as nitrogen has a larger atomic radius. During service, the precipitation of different phases takes place. In particular, the precipitation of fine and homogenously distributed intragranular Nb-CrN nitrides (Z phase) is effective in increasing the creep resistance by precipitation hardening. Additionally, the precipitation of niobium carbonitrides is seen [1, 3-4]. As the niobium content in DMV 310 N is lower than in the niobium containing material 310 Nb, the amount of niobium precipitates is also reduced. In the main, more complex and chromium containing nitrides are formed. Additionally, $M_{23}C_6$ carbides are precipitated as the MX carbide forming elements are used in the nitrides. These carbides are mainly precipitated intergranularly on the grain boundaries, so that the effect on precipitation hardening is low. However, they may strengthen the grain boundaries. Despite the formation of nitride precipitates, a high amount of nitrogen remains dissolved in the austenitic matrix. Thus, the strengthening effects of both solid solution and precipitation hardening are exploited simultaneously during service of the boiler tubes.

2.4.2 Microstructure stability

During service, the aim is for homogeneous and fine precipitation of nitrides to increase creep resistance. In the case of DMV 310 N, a complex nitride (Z phase or NbCrN) is formed. After the initial precipitation a high stability of the microstructure is desirable to keep the properties stable. Precipitation can usually be divided into three stages: nucleation, growth and coarsening. So the findings for DMV 310 N material, that the nitrogen content in nitrides and carbonitrides tend to increase with aging temperature and time, are as expected. Nevertheless, it can be seen that the growth of the nitrides is relatively slow and stable even after long term and higher temperature aging [1]. These precipitates together with solute nitrogen are considered to be effective in improving the creep rupture strength of this steel.

During aging, further precipitates are formed as mentioned before. The formation of carbides such as $M_{23}C_6$ occurs preferentially on grain boundaries which, as a result, are strengthened. However, depletion of carbon in the matrix promotes the formation of intermetallic phases such as sigma phase. By the formation of the chromium carbide $M_{23}C_6$, a remarkable amount of chromium is removed from the matrix and is no longer available to restrict corrosion. The amount of $M_{23}C_6$ carbide is restricted by a certain amount of niobium which is included in the material. NbC forms in preference to $M_{23}C_6$ carbide reducing the chromium depletion of the grain boundaries.

During service, other coarse secondary phases may form which can lead to a drop in ductility and toughness and can cause embrittlement of the material. Type 310 stainless steels are prone to sigma phase formation [5]. Sigma phase is an intermetallic phase consisting mainly of iron and chromium. During service conditions, the formation of this phase takes place according to the thermodynamic stability and kinetics of precipitation. These are influenced by the composition of the alloy and the grain size (diffusion along the grain boundaries is much faster than through the grains) [6]. In particular, an increase of nickel and/or nitrogen content is effective in suppressing sigma phase formation. But an excess of both elements gives rise to the formation of Cr_2N and Pi phase (mixed nitride) resulting also in a reduction of toughness. It is evident that the chromium content is also important with respect to the Cr_2N as well as sigma phase formation. Furthermore, the modification of other elements such as silicon and manganese is effective. In DMV 310 N material, the composition is adjusted in this way to minimise the formation of these coarse secondary phases. The solute nitrogen in the matrix contributes to microstructural stability. The formation of the undesirable coarse precipitates is limited even after aging for 10,000 h at 600 to 750 °C.

The creep rupture strength values as well as the charpy impact properties of the optimised DMV 310 N material are superior to those of other 310 stainless steels.

2.5 Corrosion resistance

Chromium is the key element influencing the corrosion behaviour of steels. The sensitivity of the material to steam-side oxidation as well as fire-side corrosion is an important factor for use in the field of boilers. The use of high sulphur coal makes the fire-side corrosion resistance of even higher importance. The corrosion rate is increased by the deposition of sulphides on the tube surface. In the range of 600 to 650 °C these sulphides are in liquid state. Free sulphur trioxide dissolves the protective oxide scale to form iron and chromium based sulphates which rapidly increases the corrosion rate. A sufficient amount of chromium is necessary in order to reform the chromia layer. This is determined by the overall amount of chromium on the one hand and the kinetics (fast diffusion along grain boundaries) on the other.

The corrosion resistance is improved by an increased chromium content, resulting in rapid formation of a dense and adhesive chromia scale. A high amount of chromium also ensures a fast reformation of this scale after deterioration. As a result, the corrosion resistance of type 310 stainless steels with a chromium content of around 25 % is superior to that of 18-8 stainless steels with about 18 % of chromium such as DMV 304 HCu or DMV 347 HFG. In general, the precipitation of chromium containing nitrides and especially the formation of $M_{23}C_6$ with a high amount of chromium results in a depletion of chromium. The formation of a chromia scale after detachment is therefore slower than for the other grades. Nevertheless, results of steam oxidation tests and hot corrosion tests in synthesized coal ash environment between 650 and 700 °C for up to 1000 h exhibit similar behaviour to that of other 310 stainless steels [1].

Even if DMV 310 N could have slightly lower corrosion resistance than the higher niobium alloyed grade 310 Nb after long term trials due to the precipitation of chromium enriched phases, the advantages of the clearly increased mechanical properties (creep resistance, high temperature strength) outweigh this.

3 Fabrication

3.1 Tube bending

Boiler tubes manufactured in steel grade DMV 310 N are generally suitable for cold and hot deformation. If hot forming is not performed using a controlled temperature process between 1175 °C and 1250 °C (2150 and 2280 °F) an additional solution annealing is required. Cold-formed tubes must be newly solution annealed if the cold deformation is too high.

If cold deformation exceeds the values given in Table 11, additional solution annealing after deformation is mandatory.

Norm	Max. cold deformation	Radius to wall thickness ratio	Additional solution annealing temperature
VdTÜV Datasheet 546	>20 %	≤ 2,5	1180-1270°C (2156-2318 °F)

In order to maintain the corrosion resistance, a new solution annealing is recommended, even after a small degree of cold deformation.

3.2 Welding

The material DMV 310 N is weldable using state-of-the-art technologies. The following fusion welding techniques are possible: metal gas-shielded welding with welding wires, welding sticks or with cored wire electrodes and metal arc welding with lime alkaline enclosed electrodes. It is necessary to use approved filler materials which are also tested at the foreseen application temperature. Preheating and heat treatment after the welding process in the fabrication of DMV 310 N is not mandatory. However, if the material is sensitised after welding, then a post welding treatment (solution treatment) can be done to restore the properties, mainly to increase the corrosion resistance [VdTÜV material data sheet 546 (03.2007)].

Generally, austenitic stainless steels have a high susceptibility to hot cracking in the weld. Welding tests have indicated similarities between niobium modified type 310 stainless steels as well as DMV 310 N and the niobium containing DMV 347 HFG material [1]. It is possible to achieve sound weld joints, but the margin of safety is narrower than for the more crack resistant steels [3]. Weld metal cracking can be controlled by the use of appropriate filler materials. Most common filler wires are Ni-materials based on alloy 617. To restrict heat affected zone cracking, a low heat input should be used and care should be taken to avoid atmospheric contamination of the molten metal.

4 References

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