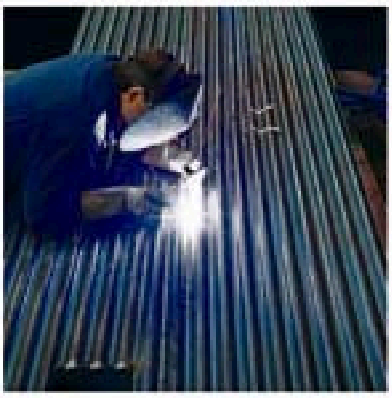
phoenix union thermanit

Welding filler metals for power plant engineering

FRAMATOME ANP

NCA 3800



EN ISO 9001

EN ISO 14001

KTA 1408

Contents

Welding Filler Metals for Creep Resistant Tube and Pipe Steels Used in Power Plant Manufacturing

Introduction

The development and production of welding consumables for creep resistant steels for power plant manufacturing have been a focus point at T-Phoenix Union Thermanit (T-PUT) for decades. Consequently, there are numerous experiences available in processing the wide range of creep resistant steels. ***Table 1*** provides an overview of the most important ferritic / bainitic and martensitic steels for fossil-fired power plants.

Table 1: Chemical composition of proven and newly developed creep resistant steels for steam boiler components

	Designation	Mat. No.	ASTM Standard	Elements in % by weight: C	Si	Mn	Cr	Ni	Mo	V	W	Nb	Other	Working temp. °C [1]
ferritic / bainitic steels	16 Mo 3	1.5415	T/P1	0,12-0,20	< 0,35	0,40-0,90	< 0,30	< 0,30	0,25-0,35	–	–	–	–	< 460
	13 CrMo 4-5	1.7335	T/P12	0,08-0,18	< 0,35	0,40-1,0	0,7-1,15	–	0,40-0,60	–	–	–	–	< 545
	15 CrMoV 5-10	1.7745	–	0,10-0,16	0,15-0,35	0,40-0,90	1,10-1,40	–	0,90-1,10	0,20-0,35	–	–	–	< 545
	15 NiCuMoNb 5 (WB 36)	1.6368	–	< 0,12	0,25-0,50	0,80-1,20	–	1,0-1,30	0,25-0,50	–	–	0,015-0,045	Cu 0,50-0,80	< 545
	20 MnMoNi 5-5	1.6310	–											
	10 CrMo 9-10	1.7380	T/P22	0,08-0,14	< 0,50	0,40-0,80	2,0-2,5	–	0,90-1,10	–	–	–	–	< 545
	HCM2S (T23)		T/P23	0,04-0,10	< 0,50	0,30-0,60	1,90-2,60	–	< 0,30	0,20-0,30	1,45-1,75	0,02-0,08	N < 0,010 B < 0,006	< 550
	7 CrMoVTiB 10-10 (T24)	1.7378	(T/P24)	0,05-0,095	0,15-0,45	0,30-0,70	2,20-2,60	–	0,90-1,10	0,20-0,30	–	–	N < 0,010 B 0,0015-0,0070 Ti 0,05-0,10	< 550
martensitic steels (9-12% Cr-steels)	X 20 CrMoV 12-1 (X20)	1.4992	–	0,17-0,23	< 0,50	< 1,00	10,0-12,5	0,30-0,80	0,80-1,20	0,25-0,35	–	–	–	< 585
	X 10 CrMoVNb 9-1 (P91)	1.4903	T/P91	0,08-0,12	0,20-0,50	0,30-0,60	8,0-9,5	< 0,40	0,85-1,05	0,18-0,25	–	0,06-0,10	N 0,030-0,070	< 585
	X11CrMoWVNb 9-1-1 (E911)	1.4905	T/P911	0,09-0,13	0,10-0,50	0,30-0,60	8,50-9,50	0,10-0,40	0,90-1,10	0,18-0,25	0,90-1,10	0,06-0,10	N 0,05-0,09	< 625
	X10CrWMoVNb 9-2 (P92)		T/P92	0,07-0,13	< 0,5	0,30-0,60	8,5-9,5	< 0,40	0,30-0,60	0,15-0,25	1,5-2,0	0,04-0,09	N 0,03-0,07 B 0,001-0,006	< 625
	X12CrCoWVNb 12-2-2 (VM 12) *		–	0,11	0,45	0,2	11,5	0,28	0,23	0,24	1,40	0,065	Co 1,3 N 0,055 B 0,003	< 650

[1] meaningful operation temperature limit in power plants from design standpoint * ongoing development in COST 536

Table 2: T-PUT welding consumables recommendations

Base material	Mat. No.	ASTM Standard	Welding process: SMAW	AWS A5.5	GTAW	AWS A5.28	SAW	AWS A5.23
16 Mo 3	1.5415	T/P1	Phoenix SH Schwarz 3 K	E7015-G	Union I Mo	ER80S-G	Union S 2 Mo UV 420 TT	EA2
13 CrMo 4-5	1.7335	T/P12	Phoenix Chromo 1	E8018-B2	Union I CrMo	ER80S-G	Union S 2 CrMo UV 420 TT	EB2R
15 CrMoV 5-10	1.7745	–	Phoenix SH Kupfer 3 K	E9015-G	–	–	–	–
15 NiCuMoNb 5 (WB36)	1.6368	–	Phoenix SH Schwarz 3 K Ni	E9015-G	Union I Mo	ER80S-G	Union S 3 NiMo 1 UV 420 TT(R)	EG (E F3 mod.)
20 MnMoNi 5-5	1.6310	–	Phoenix SH Schwarz 3 K Ni	E9018-G	Union I Mo	ER80S-G	Union S 3 NiMo 1 UV 420 TT(R)	EG (E F3 mod.)
10 CrMo 9-10	1.7380	T/P22	Phoenix SH Chromo 2 KS	E9015-B3	Union I CrMo 9-10	ER90S-G	Union S 1 CrMo 2 UV 420 TTR	EB3R
HCM2S		T/P23	Thermanit P23	–	Union I P23	ER90S-G	Union S P23 UV 430 TTR-W (UV 305)	EG
7CrMoVTiB 10-10	1.7378	T/P24 (Draft)	Thermanit P24	–	Union I P24	ER90S-G	Union S P24 UV 430 TTR-W (UV 305)	EG
X20CrMoV 12-1 (X20)	1.4922	–	Thermanit MTS 4	–	Thermanit MTS 4 Si	ER505(mod.)	Thermanit MTS 4 Marathon 543	EG
X10CrMoVNb 9-1 (P91)	1.4903	T/P91	Thermanit Chromo 9 V Thermanit Chromo T91	E9015-B9	Thermanit MTS 3	ER90S-B9	Thermanit MTS 3 Marathon 543	EB9
X11CrMoWVNb 9-1-1 (E911)	1.4905	T/P911	Thermanit MTS 911	E9015-G (E9015-B9 mod.)	Thermanit MTS 911	ER90S-G	Thermanit MTS 911 Marathon 543	EG (B9 mod.)
X10CrWMoVNb 9-2 (P92)		T/P92	Thermanit MTS 616	E9015G (E9015-B9 mod.)	Thermanit MTS 616	ER90S-G	Thermanit MTS 616 Marathon 543	EG (B9 mod.)
X12CrCoWVNb 12-2-2 (VM12) *		–	Thermanit MTS 5 CoT *		Thermanit MTS 5 CoT *	–	Thermanit MTS 5 CoT * Marathon 543	

* currently under development

Apart from the proven creep resistant steels, the latest developments like T/P23, T/P24, E911, P92 and VM 12 have also been shown. With these steels, considerable increases in the efficiency of fossil-fired power plants can be realized. In addition to the higher cost efficiency the lower consumption of raw materials simultaneously results in a reduced CO_2-emission.

T-PUT is producing suitable tried and tested VdTÜV-approved welding consumables for these creep and high temperature resistant steels. The selection of welding filler metals for these steels listed in ***Table 1*** is partially aligned with the long-term properties, especially in the case of tubes and pipes that are subjected to temperatures above 450 °C.

Table 2 shows an assignment of welding filler metals to the different base materials depending on the welding process.

Table 3 contains the chemical composition of similar welding filler metals taking the example of SMAW electrodes specifying the recommended heat treatment (PWHT) in order to achieve a sufficient impact toughness.

Table 3: Chemical composition of matching welding filler metals (SMAW) including recommended heat treatment (PWHT)

	Base metal	Filler metal acc. to EN 1599/1600	Matching welding deposit analysis											Mech. properties (all weld metal) at RT			
			C	Si	Mn	Cr	Mo	Ni	Nb	V	W	Co	N	PWHT °C / h*	YS (MPa)	TS (MPa)	Elongation (J)
ferritic – bainitic	16 Mo 3	E Mo B 42	0,08	0,30	1,20	–	0,45	–	–	–	–	–	–	(620 / 1)	520	590	150
	13 CrMo 4-5	E CrMo 1 B 42	0,08	0,30	0,90	1,00	0,50	–	–	–	–	–	–	700 / > 2	470	580	150
	15 CrMoV 5-10 GS-17 CrMoV 5-11	E CrMoV 1 B 42	0,09	0,35	1,1	1,2	1,0	–	–	0,27	–	–	–	720 / > 2	520	630	160
	15NiCuMoNb5 (WB36)	E 50 4 1 NiMo B 42 H5	0,06	0,30	1,25	0,20	0,40	1,0	(Cu = 0,08)					580 / 2	500	590	140
	10 CrMo 9-10	E CrMo 2 B 42	0,07	0,25	0,70	2,20	0,90	–	–	–	–	–	–	690 / > 2	510	620	180
	HCM2S (T 23)		0,06	0,27	0,54	2,1	0,08	0,05	0,04	0,21	1,72	–	–	740/2	509	625	136
	7 CrMoVTiB 10-10 (T24)		0,09	0,3	0,52	2,5	1,0	–	0,04	0,22	–	–	–	740/2	577	689	150
martensitic	X20 CrMoWV 12-1	E CrMoWV 12 B 42	0,18	0,25	0,5	11,5	1,0	0,6	–	0,3	0,5	–	–	760 / > 4	600	750	40
	X10 CrMoVNb 9-1 (P 91)	E CrMo 9 B 42	0,09	0,22	0,65	9,0	1,1	0,80	0,05	0,20	–	–	0,04	760 / > 2	600	750	50
	X12 CrWVNb 12-2-2 (E 911)	EZ CrMoWV 9 11 B 42	0,09	0,20	0,57	8,85	0,92	0,83	0,047	0,21	1,0	–	0,05	760 / > 2	600	750	50
	X10 CrWMoVNb 9-2 (P 92)	EZ CrMoWV 9 0,5 2 B 42	0,098	0,23	0,66	9,23	0,53	0,66	0,047	0,20	1,70	–	0,06	760 / > 2	600	750	45
	X11 CrMoWVNb 9-1-1 (VM 12)	EZ CrCoW 12 2 2	0,11	0,45	0,65	11,15	0,30	0,70	0,06	0,25	1,50	1,6	0,035	770 / > 2	600	750	> 27

Duration of annealing depends on the wall thickness

The properties of the welding filler metals must match those of the base materials. Apart from the optimised chemical composition, this is decisively influenced by the welding conditions. Therefore, the special technical features of welding application are briefly described below.

16 Mo 3 and 13 CrMo 4-5 (EN 10028 T2)

From the group of classical creep resistant steels, the material 16 Mo 3 can be processed with the familiar arc welding process without any problems. The low alloyed creep resistant steel 13 CrMo 4-5 is generally welded in quenched and tempered condition with preheating (about 250 °C). To release the residual stresses and to improve the impact toughness of the weld deposit, the joints are subjected to a stress-relief heat treatment after welding.

15 NiCuMoNb 5 (WB 36) and 20 MnMoNi 5-5

For components in power plants (including nuclear plants) as well as in chemical reactors with operating temperatures above 350 °C, high-strength fine-grained steels with the alloying concepts Ni-Mo and Ni-Cu-Mo have been used successfully for many years. The material WB 36, in particular, has worldwide gained importance, especially in power plants, as a result of the standardisation in the ASME-Code. 20 MnMoNi 5-5 was primarily developed for pressure vessels (nuclear plants).
There are high toughness requirements on these materials and hence also for the welded joints. ***Table 4*** contains the well approved welding filler metals for both steels. It has to be observed that such welded joints require a heat treatment (PWHT), i.e. a stress-relief heat treatment. This requirement has **not** been taken into consideration in the code EN 499.
Fig 1 shows the temperature cycle and the subsequent heat treatment after welding of WB 36

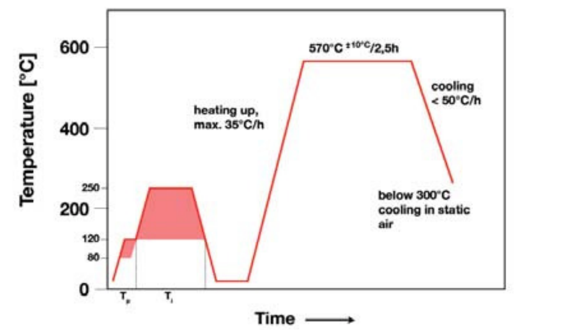


Fig. 1:

Typical temperature cycle during and after welding of WB 36

Table 4: Filler metal for creep resistant steels 20 MnMoNi 5-5 and 15 NiCuMoNb 5 (WB 36)

	Chemical composition (% by weight); all weld metal									Mech. properties of all weld metal at RT				
	C	Si	Mn	Cr	Cu	Ni	Mo	Nb	N	YS MPa	TS MPa	Elongation %	CVN (ISO-V) J	Remark
Base metal WB36	< 0,12	0,25 0,50	0,80 1,20		0,50 0,80	1,00 1,30	0,25 0,50	0,015 0,045	< 0,020	410 440	590 780	>16	0°C: 27	
Filler metal acc.:														
EN 499 - E 50 4 Mo B 42 (SH Schwarz 3 K)	0,06	0,35	0,90				0,45			U: 490 S: 480	U: 570 S. 550	U. 20 S: 21	U: 120 S: 120	for wall thickness ≤ 30 mm
EN 499 - E 50 4 1 NiMo B 42 H5 (SH Schwarz 3 K Ni)	0,06	0,30	1,25	0,20	0,08	1,0	0,40			U: 540 S: 500	U: 620 S: 590	U: 20 S: 21	U: >140 S: >140	for wall thickness >25 mm
EN 14295 - S 3 Ni1Mo T (Union S 3 NiMo 1 / UV 420 TT (R))	0,08	0,25	1,55			0,90	0,55			U: 560 S: 550	U: 680 S. 660	U: 22 S: 22	U: 140 S: 140	
EN 12070 - W MoSi (Union 1 Mo)	0,10	0,60	1,15				0,50			U: 580	U: 570	U: 23	U: 110	

U = welded condition S = after heat treatment 580 - 560 °C

15 CrMoV 5-10 / GS-17 CrMoV 5-11

Pipes as per Russian standards were used in East German power plants for temperature-stressed pipes. The steel 15 CrMoV 5-10 (15Ch1M1F) was used for live-steam pipes. This steel is a modified tube and pipe steel comparable to the cast steel GS-17 CrMoV 5-11 which has been widely used in Germany for turbine and fittings casings in the temperature range up to 550 C. The equivalent welding consumables for GS-17 CrMoV 5-11 are also approved for the tube and pipe material 15 CrMoV 5-10. The welding takes place with preheating of 200 °C and an interpass temperature of 250 °C to 300 °C. Heat treatment after the welding is required at 710 to 740 °C, with the holding duration being 3 min/mm. In case of shaped parts and wall thicknesses > 45 mm, heat treatment out of the welding heat is compulsory.

10 CrMo 9-10; ASTM A 387, Gr. 22, Cl. 2

This steel, like 13 CrMo 4-5 and 15 CrMoV 5-10, exists in the tempered state and is also air-hardening which must be specially taken into consideration while welding. In the heat affected zone (HAZ) of the base material, but also in the weld deposit itself, hard and brittle zones may occur resulting from the formation of martensite, which promote crack formation. Therefore, a preheating of 150 - 200 °C is necessary and an interpass temperature of 250 - 300 °C must be maintained. A subsequent annealing should be carried out at 690 - 730 °C. The creep rupture values for the equivalent welding consumables Phoenix SH Chromo 2 KS, Union I CrMo 9-10 and Union S1 CrMo 2 / UV 420 TTR are in excess of 30,000 h. Hence, it is possible to reduce the safety coefficient (safety coefficient 1.0 in case of SAW and 0.8 x calculation characteristic value of the base material with SMAW and GTAW).

New kinds of boiler tube steels HCM2S (T/P23) and 7 CrMoVTiB 10-10 (T/P24)

Higher steam temperatures and pressures also require higher boiler temperatures. So far, tube walls were made from the steels 16 Mo 3 and 13 CrMo 4-5. At higher design temperatures, the material characteristics of these steels do not fulfill the elevated requirements with regard to creep resistance and long-term properties. Therefore, the base materials HCM2S (T23) and 7 CrMoVTiB 10-10 (T24) were developed and qualified for tube walls. Apart from their use as thin-walled boiler tubes, these steels are also eminently suitable for thick-walled components. ***Fig 2*** shows the considerably improved long-term creep strength properties as compared with 10 CrMo 9-10 (P22). The operation temperature of these 2 1/4 Cr-steels must be limited up to max. 570 °C, since above that, intense scaling has to be expected.

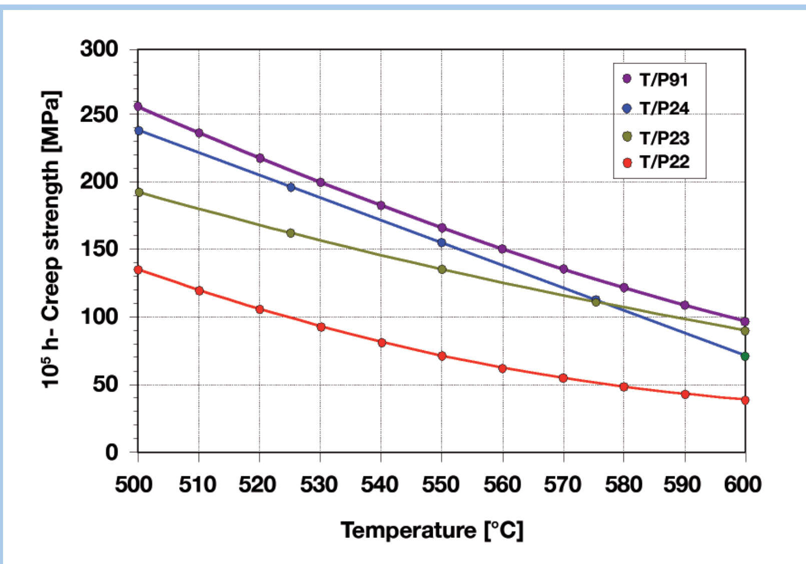


Fig 2:

100,000 h - values for the creep rupture values of T/P22, T/P23, T/P24 and T/P91 at different temperatures

Fig 3 explains the economical benefit when using these new bainitic steels with the example of a T-piece.
The advantage of these two steels with regard to the processing is the relatively low hardening in the HAZ after the welding (hardness max. 350 HV). Equivalent welding filler metals are required for these steels, too, with the demand for a sufficient toughness of the weld deposit in as-welded condition. Results of equivalent weld deposits for T/P23 are listed in ***Table 5.***

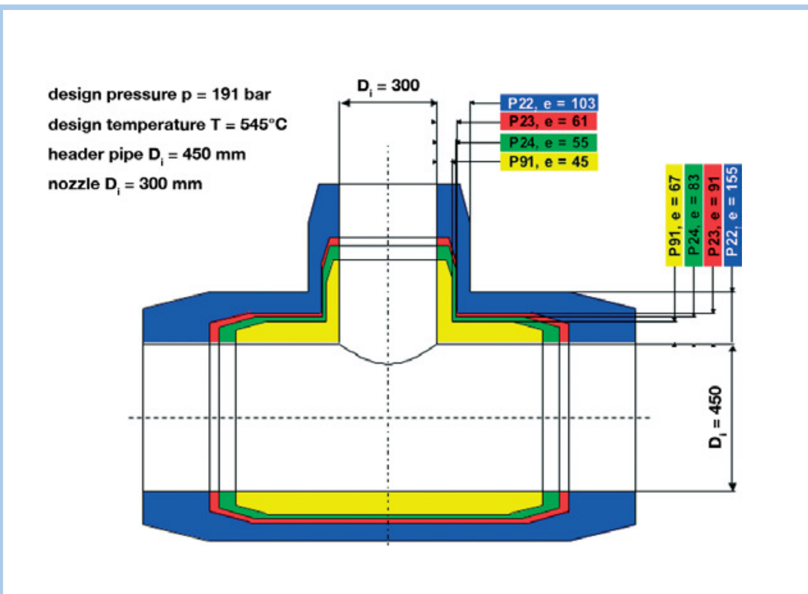


Fig 3:

Comparison of the wall thicknesses of T-pieces of P22, P23, P24 and P91 according to the calculation as per EN 13480-3

Table 5: Chemical composition and mechanical properties of matching filler metals for T/P23

Chemical composition (% by weight); all weld metal

	C	Si	Mn	Cr	Ni	Mo	V	W	Nb	N	B
GTAW	0,08	0,27	0,54	2,14	0,04	0,08	0,21	1,58	0,031	0,011	0,002
SMAW	0,06	0,22	0,46	2,28	0,12	0,02	0,28	1,72	0,043	0,017	0,002
SAW	0,05	0,27	0,94	2,04	0,09	0,11	0,19	1,61	0,043	0,007	<0,001

Mechanical properties; all weld metal

Process	PWHT (°C/h)	Testing temperature + (°C)	YS (MPa)	TS (MPa)	Elongation (%)	CVN ISO-V (J)			Hardness (HV10)
GTAW Union I P23 ø: 2,4 mm	–	20	639	818	21,4	228	230	268	270
	740/2	20	520	620	20,2	261	286	299	250
SMAW Thermanit P23 ø: 4,0 mm	740/2	20	509	625	19,0	128	136	140	227
SAW Union S P23 Flux: UV 430 TTR-W * wire-ø: 4,0 mm	740/2	20	615	702	18,1	187	204	208	237

* for welding of membrane walls UV 305

In as-welded condition, the GTAW weld deposit shows a high strength and simultaneously a high toughness and a hardness of < 300 HV. Tempering is not necessary for wall thicknesses ≤ 10 mm. In case of greater wall thicknesses or when using the SMAW or SAW process, a PWHT at 740 °C/2 h is required.

Table 6 contains results for equivalent weld deposits to T/P24. In this connection it should be noted that the welding consumables are alloyed with Nb in contrast to the base material where Ti is added; the reason is an uncontrolled Ti burn-off in the arc. The GTAW weld deposit of this alloy also shows a high strength and at the same time a high toughness in the pure weld deposit. The hardness of the GTAW weld deposit in as-welded condition is also below 300 HV 10. The welding filler metals equivalent to T24 (GTAW and SMAW) have already been used successfully in a fluidized boiler for a coal fired power plant.

At present, the welding filler metals for T/P23 and T/P24 are being qualified for further power plant deployment in different projects. In particular, the long-term properties of the weld deposits and the welded joints are being determined.

In the Scholven power plant (Germany), within the framework of the „Comtes 700“ project, Alstom installed a bypass for a steam temperature of 700 °C. A part of the tube wall was made of T24 (tubes and strip plates). Matching welding consumables produced by T-PUT were used on this project. No PWHT took place after the welding.

Table 6: Chemical composition and mechanical properties for matching filler metals for T/P24

Chemical composition (% by weight); all weld metal

	C	Si	Mn	Cr	Mo	V	N	B	Ti/Nb
GTAW	0,061	0,23	0,49	2,29	1,0	0,24	0,014	0,0020	0,041
SMAW	0,090	0,27	0,54	2,53	1,03	0,22	0,013	0,0030	0,046
SAW	0,050	0,20	0,72	2,26	0,98	0,22	0,009	0,0010	0,027

Mechanical properties; all weld metal

Process	PWHT (°C/h)	Testing temperature + (°C)	YS (MPa)	TS (MPa)	Elongation (%)	CVN ISO-V (J)			Hardness (HV10)
GTAW Union I P24 ø: 2,4 mm	–	20	664	803	19,1	298	298	298	322
	740/2	20	595	699	20,3	264	280	292	230
SMAW Thermanit P24 ø: 4,0 mm	740/2	20	577	689	18,1	154	152	148	233
SAW Union S P24 Flux: UV 430 TTR-W * wire-ø: 4,0 mm	740/2	20	495	600	23,8	260	267	282	206

* for welding of membrane walls UV 305

Martensitic steels X 20 CrMoV 12-1; P91; E911 and P92

Martensitic steels are required for live-steam and superheater pipes as well as for collectors. The steel X 20 CrMoV 12-1 was used in Germany and Europe between 1960 and 1990. From about 1990 onwards, this steel was replaced by the 9 % Cr-steel P91. ***Fig 4*** shows the lower creep strength of the X 20 CrMoV 12-1 as compared to other martensitic steels like P91, E911 or P92 as well as austenitic steels and Ni-base alloys. Due to the low C-content as compared to X 20 CrMoV 12-1, the 9 % chromium steels P91, E911 and P92 have welding advantages, since the maximum hardness after the welding is about 200 HV 10 lower (450 HV 10 to 650 HV 10).
Fig 5 shows thick-walled pipe connection of a live-steam pipe made of P91.

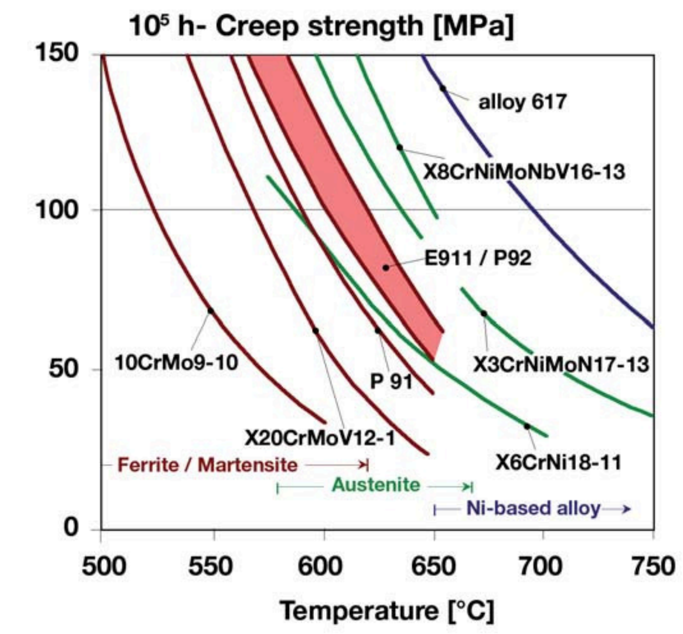


Fig 4:

Pipe steels for use in live-steam pipes of power plants

Fig 5:
Thick-walled pipe connection of a live-steam pipe of P91

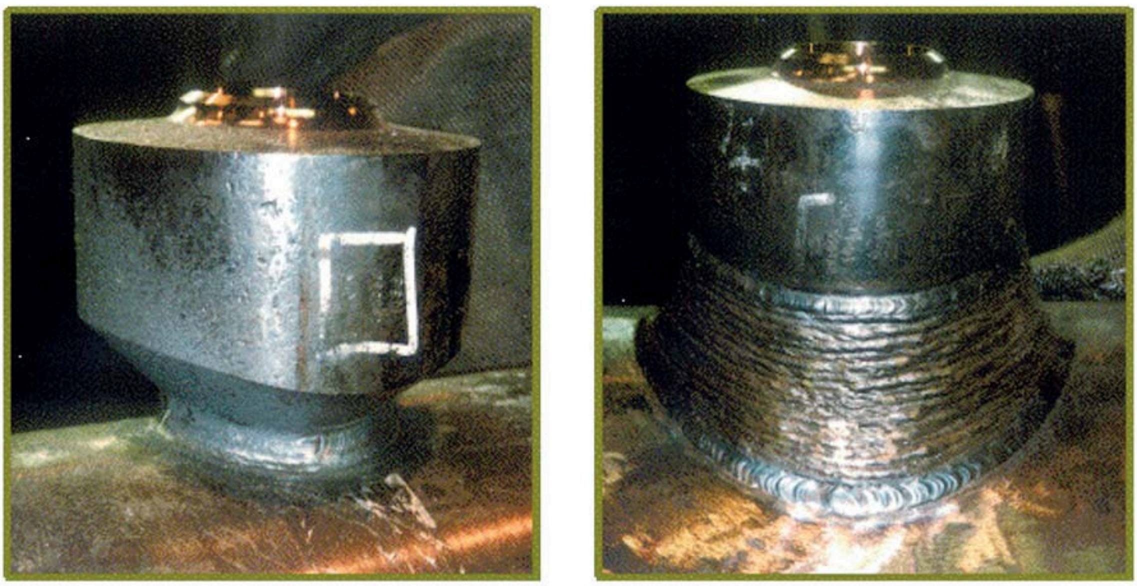


Table 7 contains typical analyses and mechanical values for the matching filler metals for P91. Apart from the optimised analysis setting and the optimised welding parameters (beads as thin as possible) the toughness of the weld deposits depends to a great extent on the PWHT-parameters.
Increasing heat treatment temperatures and holding times result in higher toughness values and lower hardness ***(Figures 6 and 7)***.

Table 7: Chemical composition and mechanical properties of SMAW, GTAW and SAW filler metals for P91

Chemical composition (% by weight); all weld metal

Process	Filler metal	Ø (mm)	C	Si	Mn	Cr	Mo	Ni	V	Nb	N
SMAW	Thermanit Chromo 9 V	3,2	0,09	0,23	0,65	9,1	1,0	0,76	0,20	0,06	0,03
GTAW	Thermanit MTS 3	2,4	0,09	0,15	0,43	9,2	1,0	0,75	0,22	0,04	0,03
SAW	Thermanit MTS 3 Flux: Marathon 543	3,0	0,09	0,22	0,32	8,7	0,9	0,71	0,22	0,05	0,036

Mechanical properties; PWHT: 760 °C/2h, test temperature +20 °C

Process	Filler metal	Ø (mm)	YS (MPa)	TS (MPa)	Elongation (%)	CVN ISO-V (J)		
SMAW	Thermanit Chromo 9 V	3,2	621	729	19,4	62	67	64
GTAW	Thermanit MTS 3	2,4	669	769	19,8	191	194	250
SAW	Thermanit MTS 3 Flux: Marathon 543	3,0	581	738	20,0	65	74	77

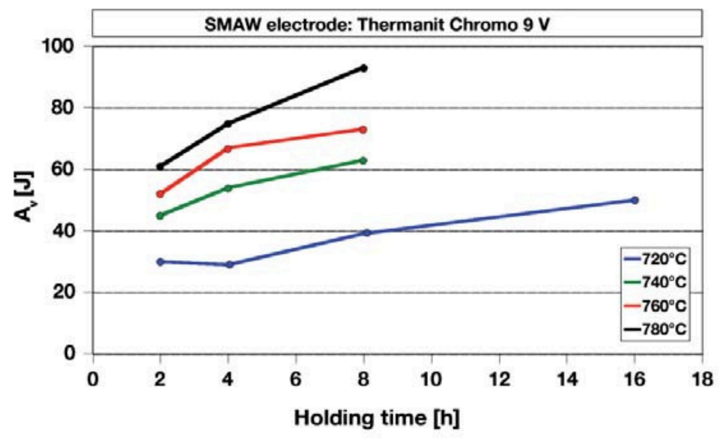


Fig 6:

Influence of PWHT-conditions on the toughness of matching filler metal to P91

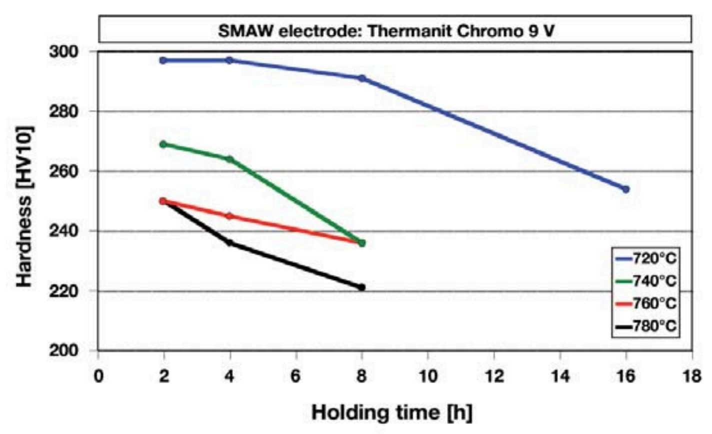


Fig 7:

Influence of PWHT-conditions (temperature / time) on the hardness at +20 °C

In ***Fig 8***, the recommended heat control during welding and the subsequent PWHT is shown for the 9 % chromium steels P91, E911 and P92. The recommended PWHT temperature of 760 °C should not be exceeded significantly, since otherwise there is the risk of promoting an austenite formation during the PWHT, which subsequently is transformed to untempered martensite.

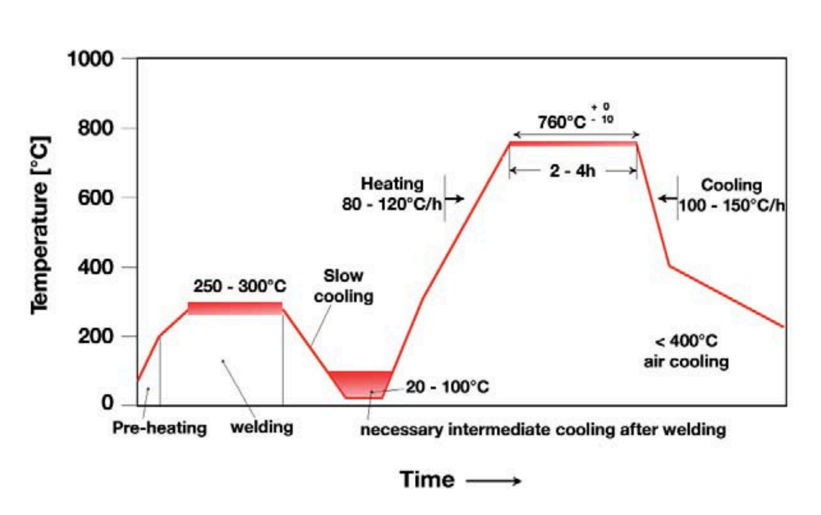


Fig 8:

Heat control during welding and subsequent PWHT of martensitic steels P91, E911 and P92

In the analysis of equivalent welding consumables for P91, E911 and P92, the contents of C, V, Nb, Mn and Ni are especially important with regard to sufficient creep strengths.
The C-content should be minimum 0.08 % in the all weld metal. When using the SAW process, special attention must be dedicated to the optimum flux selection, since most of the fluxes tend to burn off carbon. For the martensitic steels the flux Marathon 543 is available which compensates the C-burn-off.
Other analysis restrictions:

V = min 0.18 %; Nb = min 0.040 %; Mn + Ni $\leq$ 1.5 %

The limits of V and Nb are important in combination with min 0.08 % C and min 0.03 % N, in order to form sufficiently stable carbonitride precipitations which ensure the creep resistance.
Moreover, it is also important to check the Mn and Ni contents. This value must not exceed 1.5 %, since otherwise, the recommended heat treatment temperature of 760 °C is in the range of the transformation point into austenite.
Fig 9 shows the results of the creep investigations of T-PUT-filler metals for P91-weld deposits at 600 °C with a test duration of > 30,000 h. The results on the pure weld deposit are in the scatter range of the base material. This shows that T-PUT welding consumables satisfy all requirements.
The research and development team of T-PUT is carrying out long-term trials in cooperation with a reputed tube manufacturer. These tests are indispensable to be able to carry out calculations for the highly stressed components with proven characteristic values. Results from short-time trials (Iso-Stress tests) and subsequent extrapolations with Larsen Miller parameters for 100,000 h gave unrealistically high values as many comparisons have shown.

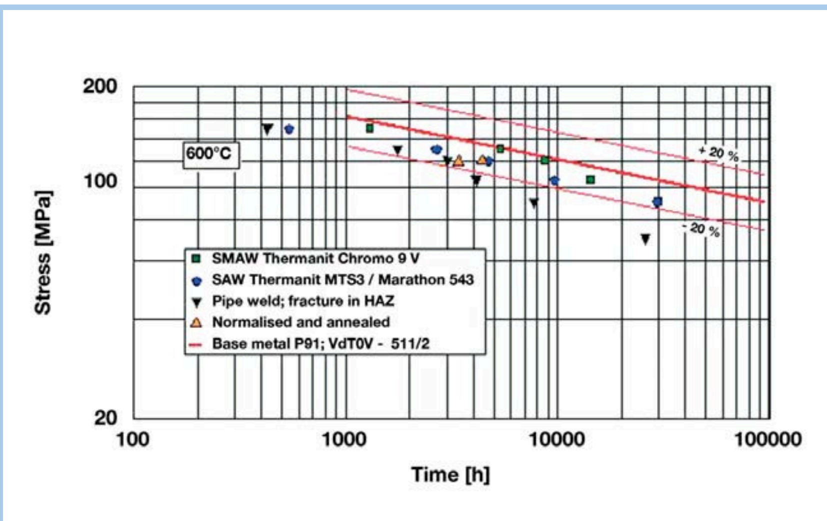


Fig 9:

Creep rupture strength data for P91 matching filler metals

Table 8 contains analyses and mechanical properties of matching filler metals for E911. Also in this case, long-term trials were carried out for > 30,000 h. ***Fig 10*** shows examples of results for the pure weld deposit at 600 °C. Once again, it can be seen that the fracture points are located within the scatter range of the base material, and that the T-PUT welding filler metals meet the requirements completely.

Table 8: Chemical composition and mechanical properties of matching filler metals to E911 (P911)

Chemical composition (%); all weld metal

Process	Type	Ø (mm)	C	Si	Mn	Cr	Mo	Ni	V	Nb	W	N
SMAW	Thermanit MTS 911	4,0	0,11	0,21	0,61	8,96	0,97	0,60	0,18	0,040	0,94	0,06
GTAW	Thermanit MTS 911	2,4	0,11	0,39	0,44	8,96	0,97	0,58	0,21	0,060	1,03	0,04
SAW	Thermanit MTS 911 Flux: Marathon 543	3,2	0,10	0,38	0,59	8,99	0,89	0,74	0,18	0,045	0,90	0,06

Mechanical properties at + 20 °C after PWHT

Process	Type	PWHT °C/h	Ø (mm)	YS (MPa)	TS (MPa)	Elongation (%)	CVN ISO-V (J)
SMAW	Thermanit MTS 911	760/2	4,0	626	765	19,2	68
GTAW	Thermanit MTS 911	760/0,5	2,4	698	813	19,4	94
SAW	Thermanit MTS 911 Flux: Marathon 543	760/4	3,2	685	798	19,8	53

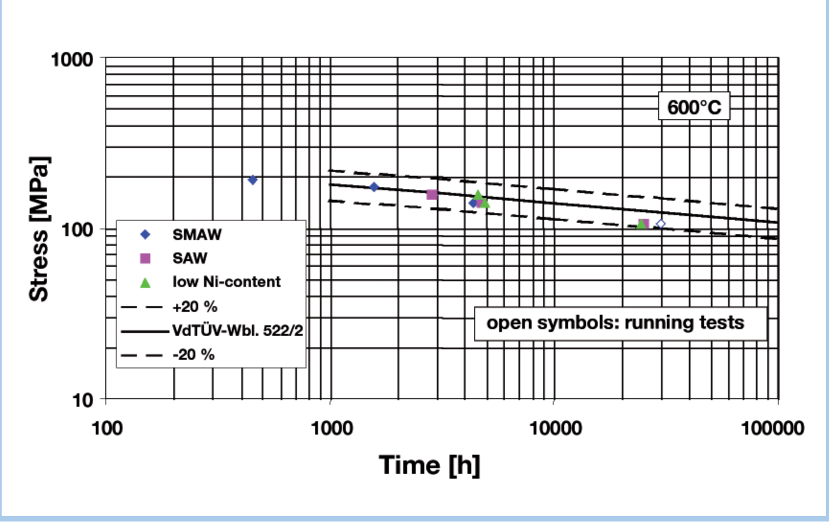


Fig 10:

Results of creep rupture tests of all weld metal (matching E911)

Fig 11 shows a boiler header made of P92. It was the first use of P92 in a German power plant (Repair procedure 1997 by Alstom). T-PUT supplied the matching welding consumables ***(Table 9)***.
With these welding filler metals, creep strength investigations > 30,000 h were also carried out ***(Fig 12)***. Once again, it was possible to prove that the filler metals produced by T-PUT meet the requirements of the base material.

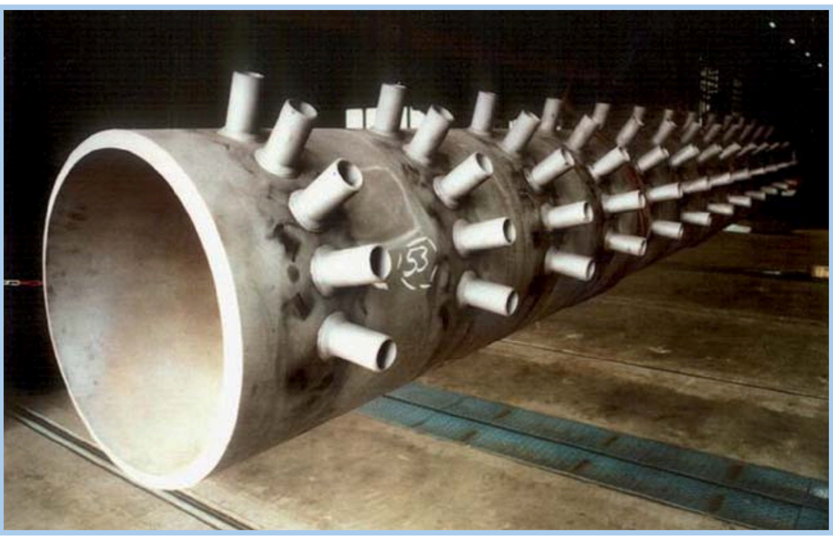


Fig 11:

Live-steam collector of P92

Table 9: Chemical composition and mechanical properties of matching filler metals for P92

Chemical composition (%); all weld metal

Process	Type	Ø (mm)	C	Si	Mn	Cr	Mo	Ni	V	Nb	W	N	B
SMAW	Thermanit MTS 616	4,0	0,11	0,27	0,65	8,95	0,53	0,70	0,19	0,044	1,72	0,045	+
GTAW	Thermanit MTS 616	2,4	0,10	0,36	0,44	8,89	0,41	0,72	0,23	0,069	1,75	0,052	+
SAW	Thermanit MTS 616 Flux: Marathon 543	3,2	0,09	0,36	0,60	8,45	0,41	0,73	0,17	0,040	1,59	0,059	+

Mechanical properties at + 20 °C after PWHT

Process	Type	PWHT °C/h	Ø (mm)	YS (MPa)	TS (MPa)	Elongation (%)	CVN (ISO-V) (J)
SMAW	Thermanit MTS 616	760/2	4,0	675	800	17,6	54
GTAW	Thermanit MTS 616	760/0,5	2,4	751	854	19,6	64
SAW	Thermanit MTS 616 Flux: Marathon 543	760/4	3,2	621	742	20,8	53

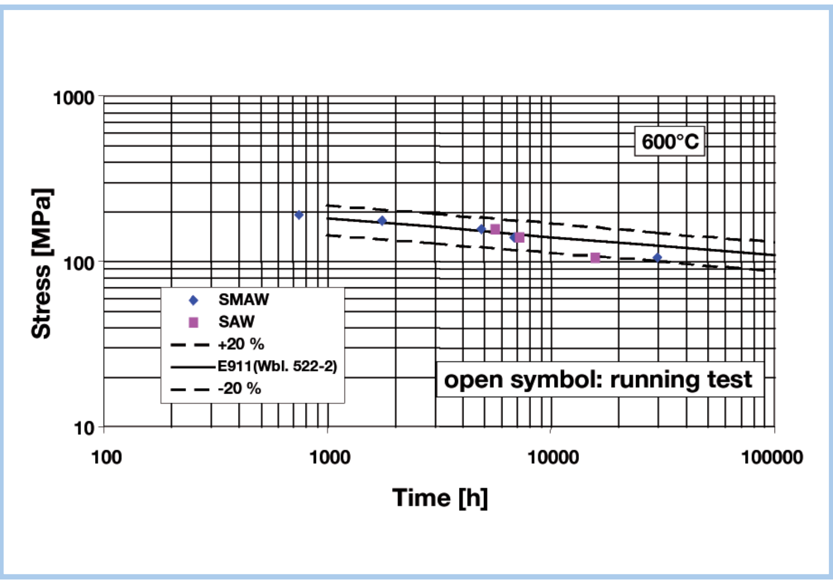


Fig 12:

Results of creep rupture tests of all weld metal (matching P92)

A new 12 % martensitic chromium steel – VM 12

The previously described base materials E911 and P92 are used, according to all the knowledge gathered so far, up to max. 620 °C. The reason is the insufficient scaling resistance at higher temperatures. Here, materials with a higher Cr-content are required. In the European research program „COST 536“, a 12% chromium steel (VM 12) developed by Vallourec + Mannesmann is being optimised and qualified up to max. 650 °C. T-PUT is playing a decisive role in this project and is developing the equivalent welding filler metal Thermanit MTS 5 CoT for VM 12.
Table 10 contains analyses and mechanical properties of matching weld deposits of the current development status.

Table 10: Matching filler metals for the 12 % Cr-steel VM 12 (Thermanit MTS 5CoT)

Chemical composition (% by weight); Base material and all weld metal

	C	Si	Mn	Cr	MO	Ni	V	W	B	Co	N	Nb
Base metal VM 12	0,11	0,45	0,20	11,50	0,28	0,23	0,24	1,40	0,003	1,30	0,056	0,065
GTAW	0,12	0,51	0,39	11,60	0,28	0,30	0,26	1,51	0,005	1,63	0,064	0,05
SMAW	0,11	0,45	0,65	11,15	0,30	0,70	0,25	1,50	0,003	1,60	0,055	0,06
SAW	0,10	0,50	0,60	11,30	0,29	0,65	0,23	1,50	0,003	1,60	0,058	0,04

Mechanical properties; all weld metal

Process	Ø (mm)	PWHT (°C/h)	YS (MPa)	TS (MPa)	Elongation (%)	CVN ISO-V (J) at +20 °C			+50 °C			Hardness (HV10)
GTAW	2,4	770/2	767	906	17,5	50	23	32	–	–	–	295
SMAW	4,0	770/2	694	835	16,0	46	34	42	57	66	58	254
SAW	3,0	770/4	688	819	18,4	36	48	46	–	–	–	275

Quality assurance, competence

T-PUT has, for decades, been a competent and reliable partner for applications in the power plant sector.
This is valid for the delivery of welding consumables as well as for solving welding engineering problems.
Our production fulfills all the requirements of the power plant operators and fabricators. Our approved production is certified according to EN ISO 9001 and EN ISO 14001, KTA 1408 as well as ASME, NCA 3800 and by Framatome. Many years of cooperation with tube manufacturers, engineering companies, piping manufacturers and equipment manufacturers lead to the corresponding know-how in this challenging segment. Like no other manufacturer of welding consumables, we carry out intensive developments of creep and heat resistant filler metals. Special emphasis is put particularly on broad-based creep strength investigations, which provide greater safety for the fabricators regarding the selection of the welding filler metals. These experiences are being used by customers in the challenging and responsible welding tasks in power plant manufacturing.

Standardisation of the welding filler metals for creep resistant steels

SMAW electrodes	**EN 1599**	or	**AWS A 5.5**
Bare wires / rods	**EN 12070**	or	**AWS A 5.28**
Flux-cored wires	**EN 12071**	or	**AWS A 5.28**
Submerged-arc welding flux	**EN 760**		
Submerged-arc welding wires	**EN 12070**	or	**AWS A.523**

Submerged-arc welding fluxes for creep resistant steels

UV 305:	**for welding membrane walls (16 Mo 3 - P24)**
UV 306:	**16 Mo 3**
UV 420 TT:	**16 Mo 3; 13 CrMo 4-5; 10 CrMo 9-10**
UV 420 TTR:	**16 Mo 3; 13 CrMo 4-5; 10 CrMo 9-10**
UV 430 TTR-W:	**P23; P24**
Marathon 543:	**X20 CrMoV 12-1; P91; E911; P92; VM 12**

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- Alstom Power Boilers, Poland
- Anhui Electricity Construction Co. Ltd., China
- Ansaldo Energia S.p.A., Italy
- Azco, USA
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- Babcock Borsig Power, Germany
- Babcock Borsig Power, United Arab Emirates
- Babcock Borsig Service, Germany
- Babcock & Wilcox Beijing Co. Ltd, China
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- Beijing Electricity Construction Co. Ltd., China
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