ZAVARIVANJE RAZNORODNIH MATERIJALA

WELDING OF DISSIMILAR MATERIALS

Russel FUCHS[1)], **Herbert HEUSER**[2)], **Bernd HAHN**[3)]

Ključne riječi: raznorodni materijali, energetska postrojenja, zavarivanje

Key words: dissimilar materials, power plants, welding

Sažetak: U energetskim postrojenjima loženim fosilnim gorivima zahtijevani su odgovarajući materijali koji odgovaraju različitim temperaturnim i oksidacijskim uvjetima koji su prisutni u kotlovima i sekcijama pregrijača. Čelične cijevi sa 2,25 Cr (T/P22; T/P23; T/P24) trebaju se zavariti sa 9 - 12 % Cr čelicima (T/P91; T/P92). U ovom području od presudnog značaja za kvalitetu spoja je izbor odgovarajućeg dodatnog materijala za zavarivanje. Ovaj rad naglašava mogućnosti postizanja optimalne kvalitete zavara različitih raznorodnih materijala u uvjetima smanjene difuzije ugljika.

Abstract: In fossil fuel fired power plants, appropriate materials are required which correspond to the different temperature and oxidizing conditions in the boiler and in the super-heater sections. Pipe steels with 2,25 Cr (T/P22; T/P23; T/P24) must be welded with 9 - 12 % Cr steels (T/P91; T/P92). In this area, the choice of the appropriate welding filler material is decisive for the quality of the connection. This report highlights the possibilities for achieving optimal qualities in different dissimilar metal welds under conditions of reduced carbon diffusion.

[1)] Böhler Welding Group USA, Inc., Houston, Texas
[2)] Böhler Schweisstechnik Deutschland GmbH, Hamm, Germany
[3)] Vallourec & Mannesmann Deutschland GmbH, Düsseldorf, Germany

1. INTRODUCTION

The increase of the steam parameters temperature and pressure in fossil fuel fired power plants and the related improvements to levels of efficiency have only been made possible through the use of new materials. The choice of the materials depends on the steam parameters in the particular sections. Concepts concerning the materials in the steam turbines, including the turbine housing, the steam generator (boiler) and the super-heater pipes must be reconsidered. New materials are available in all sections which allow both higher temperature and pressure levels. In many cases, conventional materials such as 16Mo3, P22 (10CrMo9-10) or 13CrMo4-5 are no longer satisfying increased stress levels. For this reason, new materials are now being taken into consideration in the construction of power plants. Table 1 gives an overview of chemical composition and mechanical property of the bainitic and martensitic power plant steels that are being used in the new generation of power plants.

During the construction of the different power plant components, dissimilar metal welds occur between the materials listed in Table 1. The specific features that occur during construction are generally known from the operational application of the steels used up to the present time. This primarily concerns the occurrence of de-carburized and carburized zones. Much has been reported on this subject [1 – 3]. There is very little research data available about the material pairing of the new power plant steels.

Table 1. Chemical composition and mechanical properties of new types of bainitic and martensitic materials compared to tested creep resistant materials P22, X20 and P91

Designation	**Chemical composition in weight, %**										**Working temp. /°C** [1]
	C	**Si**	**Mn**	**Cr**	**Ni**	**Mo**	**V**	**W**	**Nb**	**Others**	
Bainitic Steels											
T/P22 (10CrMo9-10)	0,08 - 0,14	≤ 0,50	0,40 - 0,80	2,0-2,5	-	0,90 - 1,10	-	-	-	-	≤ 550
T/P23 (7CrWVNb9-6)	0,04 - 0,10	≤ 0,50	0,10 - 0,60	1,9-2,6	-	0,05 - 0,30	0,20 - 0,30	1,45 - 1,75	0,02 - 0,08	N ≤ 0,03 B 0,0005-0,0060	≤ 550
T/P24 (7CrMoVTiB10-10)	0,05 - 0,10	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)											
X20CrMoV11-1	0,17 - 0,23	< 0,50	< 1,0	10,0 - 12,5	0,30 - 0,80	0,80 - 1,20	0,25 - 0,35	-	-	-	≤ 560
T/P91 (X10CrMoVNb9-1)	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 0,03-0,07	≤ 585
T/P92 (X10CrWMoVNb9-2)	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	≤ 620
[1] constructive depicted limit of working temperature in power stations											

Mechanical properties at RT

	YS MPa	TS MPa	Elongation %	CVN (ISO-V) J
T/P22 (10CrMo9-10)	≥ 310	480-630	≥ 18	> 40
T/P23 (7CrWVNb9-6)	≥ 400	≥ 510	≥ 20	-
T/P24 (7CrMoVTiB10-10)	≥ 450	585-840	≥ 17	≥ 41
X20CrMoV11-1	≥ 500	700-850	≥ 16	≥ 39
T/P91 (X10CrMoVNb9-1)	≥ 450	620-850	≥ 17	≥ 41
T/P92 (X10CrWMoVNb9-2)	≥ 440	620-850	≥ 17	≥ 27

The aim of this paper is to provide a targeted presentation of dissimilar metal welds on these new power plant steels.

2. DISSIMILAR METAL WELDS

The issue concerning dissimilar metal welds between materials with different Cr contents basically exists in the form of carbon diffusion. The carbon diffuses to the material with the higher chrome content during the heat treatment subsequent to the welding. As a result, a carbon depleted zone develops in the material with the lower chrome content, and a zone with enriched carbon, the so-called carbide seam, develops in the material with higher amount of chrome. The size of these zones depends on the ignition temperature and the annealing time. Unless the welding is carried out with nickel-based welding filler, this is generally unavoidable.

Figure 1 shows a schematic presentation of the carbon diffusion with the example of the weld joint of 10CrMo9-10 with X20CrMoV11-1 and with the use of different welding filler metals.

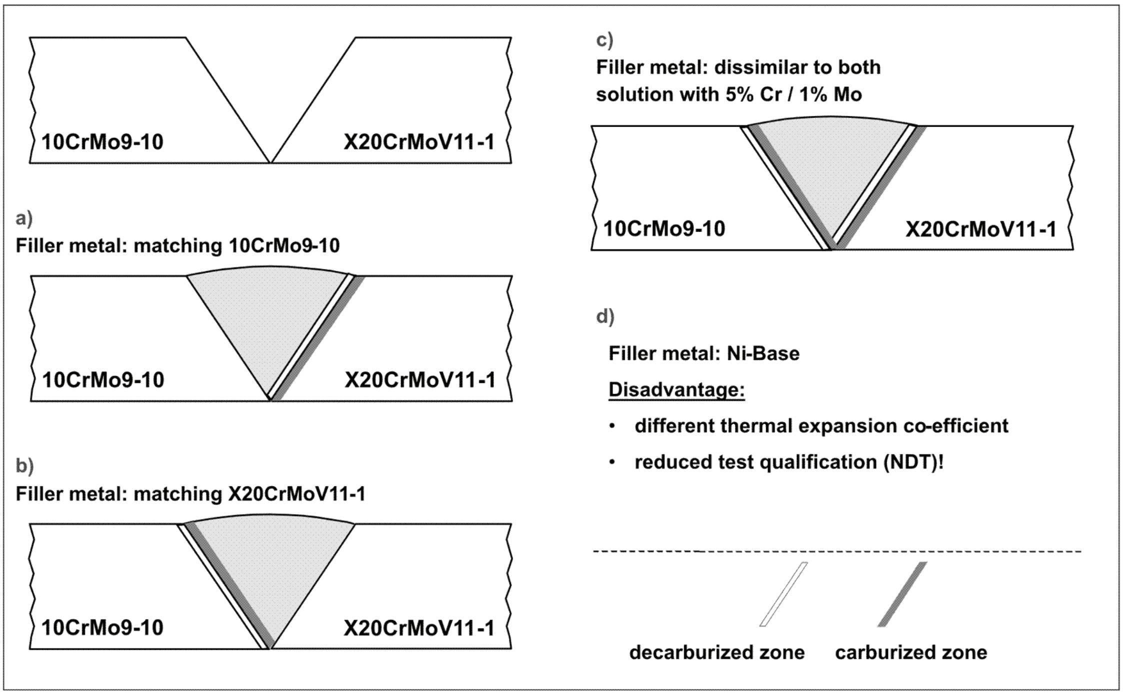


Figure 1. Schematic representation of C-diffusion for example at the dissimilar joint P22 (10CrMo9-10) – X20CrMoV11-1

The structural changes influence the material behavior (toughness and strength) of the welded joint in the area of the de-carburized and carburized zones.

On dissimilar metal welds between X20CrMoV11-1 and P22, welded to either one of the two materials in the matching way, the toughness values of the unaffected base material in the seam section of the C-depletion zone and the carbide seam are often not achieved. A high scatter of the individual measured values is reported [1, 2]. Additional analyses showed that fissure initiation and fissure progress are limited in the notched bar impact test on the softer de-carburized zone [3]. As a result of this behavior, determined in the notched bar impact test, effects during a pressure test have never been determined. Concerning the operational behavior during the operational temperature, there is also no cause for concern, as sufficiently high toughness levels occur at these temperatures. Creep strength damage in these dissimilar metal welds, which can be observed far in excess of 100,000 h operational times, has not yet been reported [3]. Even using creep tests with grooves in the de-carburized zone it was not possible to observe any premature break [2].

In the case of connections between martensitic materials such as X20CrMoV11-1 with P91 (X10CrMoVNb9-1) for example, due to the small differences between both materials in terms of Cr content, it is to be concluded that carbon diffusion does not occur at all, or only to a very negligible degree, irrespective of the filler material chosen.

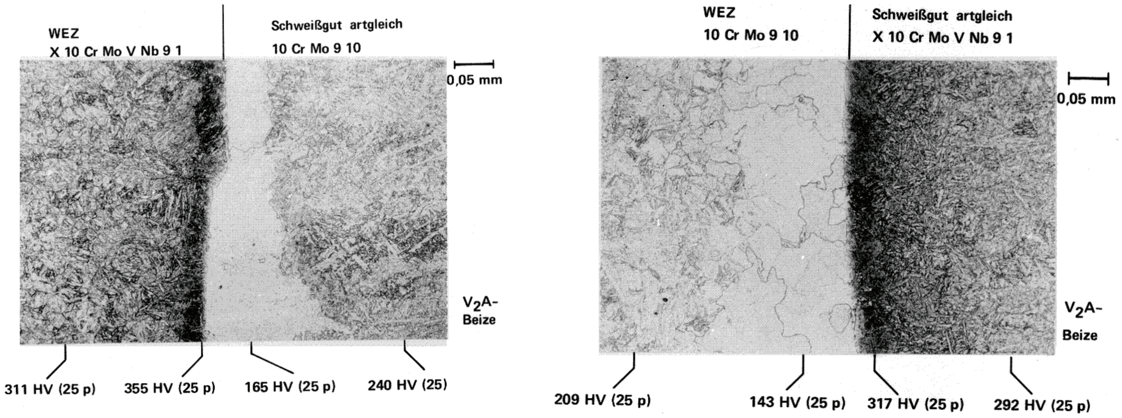


Figure 2. Decarburized zone in dissimilar joints P91 / P22; similar welded to P22 resp. to P91 [3]

In dissimilar metal welds between P22 (10CrMo9-10) and P91 (X10CrMoVNb9-1), the carburizing and/or partial de-carburization features appear considerably more strongly, irrespective of the welding filler metal used. The weak point of the joint is either in the partially de-carburized HAZ sections of the P22 welded in the matching way as P91 or in the de-carburized weld metal seam welded in the same way as P22 (see Figure 2). On the basis of extensive section tests it has been proven that during a notched bar impact test, with these dissimilar metal welds, the initiation of fissures generally occurs in the C-depleted and hence softer zones [3].

3. PRESENT APPROACH

In the previous examples, slowing down the C-diffusion in the material P22 was not possible due to a lack of special carbide forming elements such as Nb, V or Ti. With the newer bainitic materials, T/P23 and T/P24 however, such elements are important alloy ingredients which significantly improve the degree of creep strength. It is expected that these carbide forming elements also have a beneficial effect with regard to C-depleted zones of dissimilar metal welds of the martensitic materials that have a higher Cr content, T/P91 and T/P92. This is investigated through corresponding experiments as reported below.

4. EXPERIMENTAL WORK

The following material pairs were welded and tested:

a) Boiler tubes T23/T91
b) Boiler tubes T24/T91
c) Lead pipes P23/P92

For the T24/T91 material pair, there were no pipes with approximately the same diameters available.

Matching welding fillers were used to both pipe materials. Table 2 contains the analyses and mechanical properties of the welding fillers used.

Table 2. Chemical composition and mechanical properties of the engaged filler metals

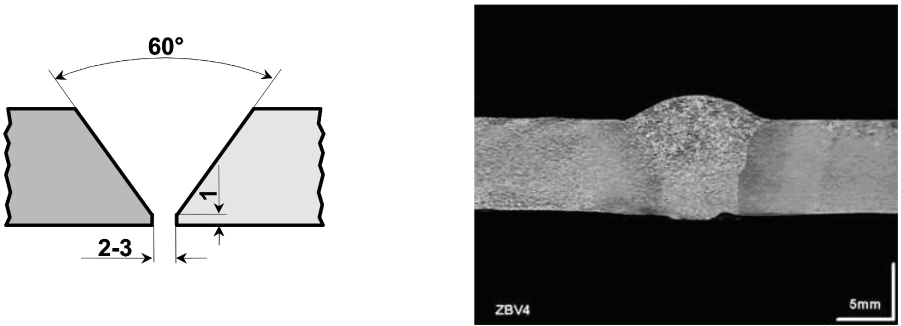
Chemical composition wire resp. all-weld-metal (weight-%)

Filler metal	**C**	**Si**	**Mn**	**Cr**	**Mo**	**Ni**	**Nb**	**N**	**V**	**W**	**Cu**	**B**	**Ti**
GTAW; similar to P23 Ø 2,4 mm	0,061	0,45	0,53	2,02	0,03	0,13	0,04	0,01	0,22	1,78	0,10	0,002	0,005
GTAW; similar to P24 Ø 2,4 mm	0,073	0,26	0,45	2,32	0,92	0,09	0,01	0,006	0,25	<,002	0,17	0,002	0,086
SMAW; similar to P23 Ø 3,2 mm	0,057	0,23	0,62	2,20	0,03	0,05	0,04	0,022	0,20	1,59	0,06	0,002	<,001

Mechanical properties all-weld-metal; test temp. +20 °C

Filler metal	**PWHT [°C/h]**	**YS [MPa]**	**TS [MPa]**	**Elongation [%]**	**CVN, ISO-V [J]**
GTAW; similar to P23 Ø 2,4 mm	740/2	621	708	21,0	256 / 207 / 242
GTAW; similar to P24 Ø 2,4 mm	740/2	595	699	20,5	264 / 286 / 292
SMAW; similar to P23 Ø 3,2 mm	750/2	523	633	20,8	100 / 137 / 144

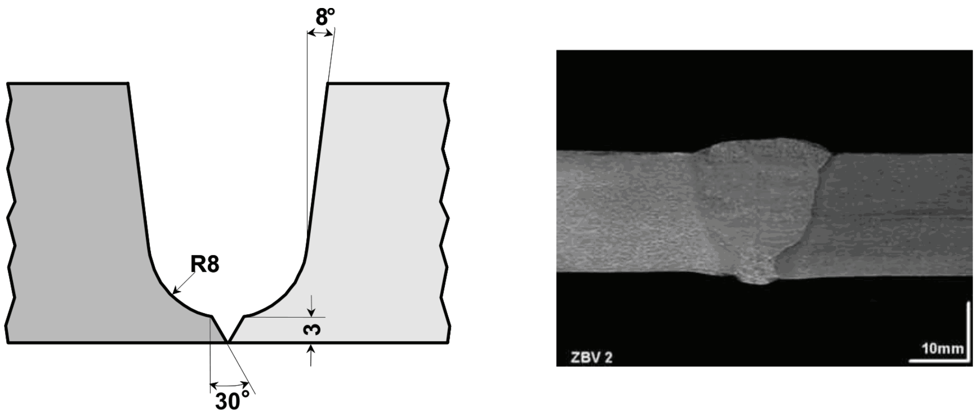
The thin-walled boiler pipe connections were TIG welded. With the thick-walled connections P23/P92, the TIG root and additional fill locations were welded with stick electrodes. The seam preparations, construction of the seam as well as data concerning the welding parameters, are shown in Figures 3 and 4.



Filler metal: GTAW, matching T23, Ø 2.4 mm

Tube dimension: 44,5 x 7,14 (mm); T_p = 150°C, T_i = 150°C, I_s = 140 A

Figure 3. Edge preparation and welded joint T23/T91 resp. T24/T91



Filler Metal, root: GTAW; matching P23 resp. matching P92, Ø 2.4 mm

Filler Metal fill passes: SMAW; matching P23 resp. matching P92, Ø 3.2 / 4.0 mm

Pipe dimension: 219 x 20 (mm); T_p **= 200°C,** T_i **= 270°C,** I_s **= 160 A**

Figure 4. Edge preparation and welded joint P23/P92

With the boiler pipe connections, the pre-heating and interpass temperatures were 150 °C. The thick-walled components P23/P92 were pre-heated to 200 °C. The max. interpass temperature was 270 °C. All connections were heat treated subsequent to welding.

5. TEST RESULTS

5.1 Mechanical properties

The mechanical properties of the connection welds were determined in as welded condition and subsequent to heat treated condition in order to determine whether a break point change occurs in connection with conditioning status during the crosscut test.

The strength behavior of the connections was established using flat bar tension specimens across the seam at room temperature and at 500 °C. All specimens fractured in the correspondingly low-resistance base material. Hence, the specified lowest tensile strength of the base materials T23, T24 and P23 were achieved.

The highest levels of toughness are achieved with the application of matching weld fillers to the low alloyed pipe material.

Tables 3 – 5 contain the mechanical properties determined. Figures 5 and 6 clearly show that the matching weld metal to P92 and to P23 demonstrates a higher level of solidity than the base material P23.

Table 3. Mechanical properties of dissimilar welds T23 / T91; GTA welded

Filler metal: matching T23, Ø 2,4 mm; Tube material T23 (44,5 x 7,6 mm) to T91 (44,5 x 7,14 mm)

PWHT [°C/min]	Test temp. + [°C]	TS [MPa]	Location of fracture	CVN centre WM [J/cm²] at +20 °C	Side bend test
740/30	20	563	BM T23	73/95/158	180° passed
	500	436	BM T23		

It can be concluded from this that no significant de-carburization is present that influences the solidity behavior in the areas the connections near the line of fusion.

This was substantiated by metallographic examinations.

Table 4. Mechanical properties of dissimilar welds T24 / T91; GTA welded

Filler metal: matching P24 (Ti/B-alloyed), Ø 2,4 mm; Tube material T24 (38,3 x 6,3 mm) to T91 (44,5 x 7,14 mm)

PWHT [°C/min]	Test temp. + [°C]	TS [MPa]	Location of fracture	CVN centre WM [J/cm^2] at +20 °C	Side bend test
740/30	20	574	BM T24	135/152/148	180° passed
	500	464	BM T24		

Table 5. Mechanical properties of dissimilar welds P23 / P92; SMA-welded; Root pass GTAW

Filler metal: matching P23, Ø 3,2 / 4,0 mm; Pipe dimension: both 219,10 x 20 mm

PWHT [°C/h]	Test temp. + [°C]	TS [MPa]	Location of fracture	CVN [J] at + 20°C	Side bend test
740/2	20	613		138/136/132 132/135	180° passed
		598			
	500/550	432/386			

Filler metal: matching P92, Ø 3,2 / 4,0 mm; Pipe dimension: both 219,10 x 20 mm

PWHT [°C/h]	Test temp. + [°C]	TS [MPa]	Location of fracture	CVN [J] at + 20°C	Side bend test
740/4	20	589		40/46/44	180° passed
		590			
	500/550	419/385			

Table 6. Used matching filler metals in this investigation

	Matching			
	T/P23	**T/P24**	**T/P91**	**P92**
GTAW	Union I P23	Union I P24	Thermanit MTS 3	Thermanit MTS 616
SMAW	Thermanit P23		Thermanit MTS 3	Thermanit MTS 616

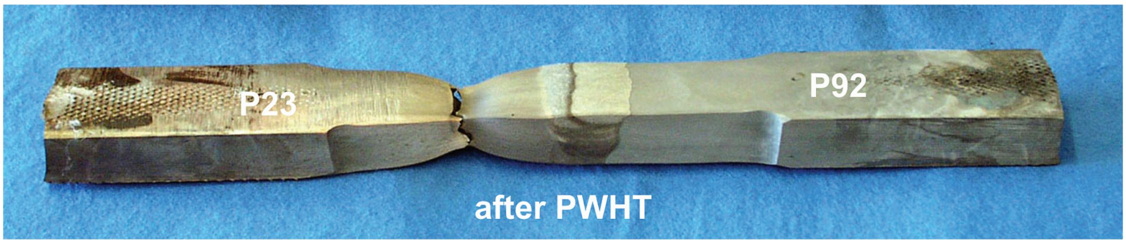


Figure 5. Tensile test specimen of the weld P23 / P92, filler metal matching P23; tested at RT

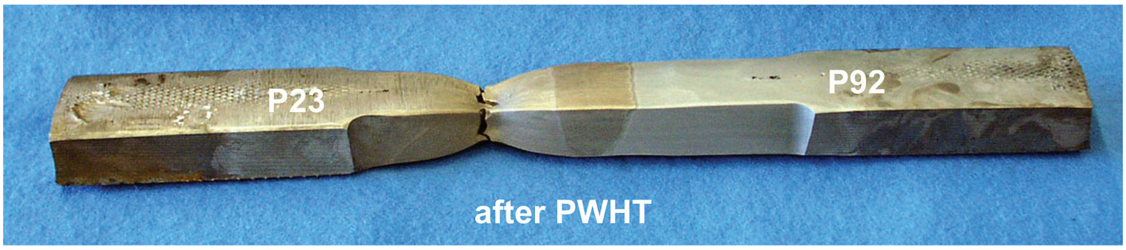


Figure 6. Tensile test specimen of the weld P23 / P92, filler metal matching P92; tested at RT

5.2 Metallography, hardness and element distribution

Through metallographic study of weldments, the areas near the fusion line were tested in order to investigate de-carburization and carburization.

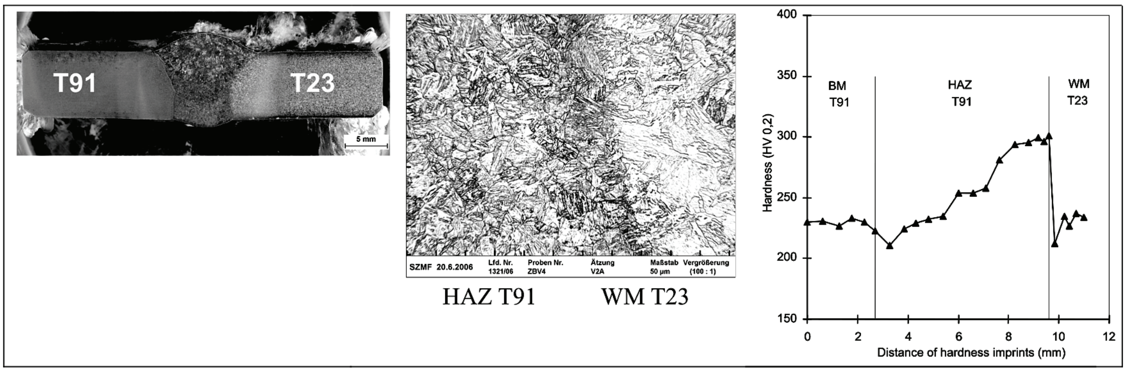


Figure 7. Microstructure in HAZ of T91 and Hardness across weldments of dissimilar joint T91 / T23; filler metal matching T23 (PWHT 740 °C / 30 min.)

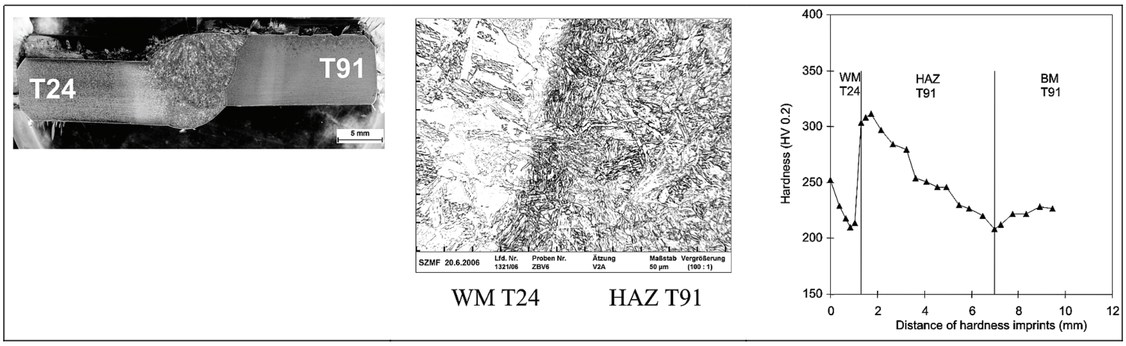


Figure 8. Microstructure in HAZ of T91 and Hardness across weldments of dissimilar joint T24 / T91; filler metal matching T24 (PWHT 740 °C / 30 min.)

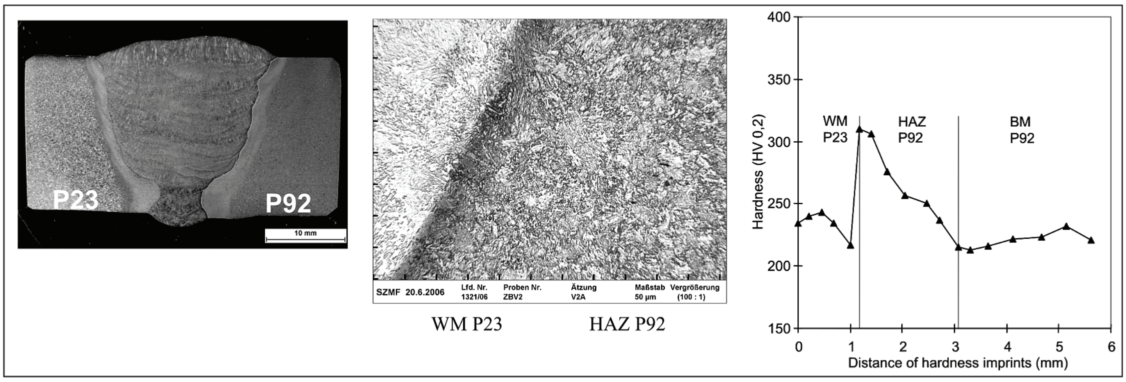


Figure 9. Microstructure in HAZ of T91 and Hardness across weldments of dissimilar joint P23 / P92; filler metal matching P23 (PWHT 740 °C / 2 h)

Figures 7 – 10 show the results of the metallographic investigations. The hardness of the weld metal in the area near the line of fusion and the HAZ does not fall below the hardness of the base material in any case. The carbon building elements in the matching weld metals to T/P23, T/P24 and P92 prevent a strong C-diffusion, as present in weld metal on P22 (Figure 2). Tests on the element distribution were also done in an electron beam microprobe which confirms these assumptions. In this way, it is possible that the creep strengths of such dissimilar metal welds are comparable with the matching connections of the low resistance pipe metals. Tests those are now underway to confirm this.

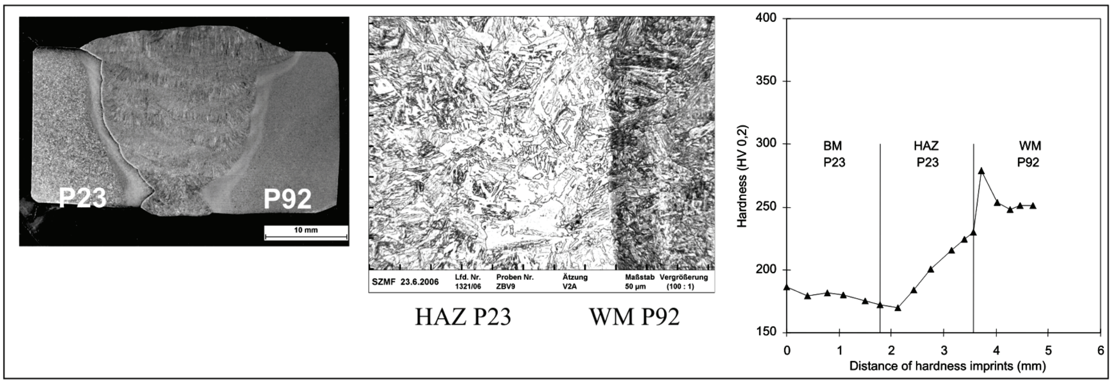


Figure 10. Microstructure in HAZ of T91 and Hardness across weldments of dissimilar joint P23 / P92; filler metal matching P92 (PWHT 740 °C / 4 h)

6. SUMMARY

The characteristics of the dissimilar metal welds of the new power plant steels T23 / T91; T24 / T91 und P23 / P92 were tested.

In comparison with the previous dissimilar metal welds P22 / P91 the special carbon forming elements V, Nb and Ti either prevent or reduce the degree of C-diffusion, irrespective of whether the same weld metals are chosen for the low alloyed pipe steels or for the higher alloyed materials. This should have a positive effect on the creep strength qualities of dissimilar metal welds of this kind. Corresponding tests have been carried out to study these effects.

With the weld metals matching T/P23 and T/P24, welding fillers are available which should also lead to a reduction of the C-diffusion with dissimilar metal welds of steels in which a partner does not contain any special carbide forming elements, which are advantageous for the P22 / P91 material pairing, for example.

Additional tests with the new, low alloyed welding fillers presented here support their application advantage when compared to the previously customary welding solutions with dissimilar metal welds.

Data concerning the product symbols of the weld filler materials used may be extracted from Table 6.

7. REFERENCES

[1] Düren, C.; Jahn, E.; Langhardt, W.; Schleimer, W.: Kerbschlagbiegeversuche an Schweißverbindungen zwischen den Stählen X20CrMoV12-1 und 10CrMo9-10; Stahl und Eisen 102 (1982); (Notched bar impact tests between the steels X20CrMoV12-1 and 10CrMo9-10; Stahl und Eisen 102 (1982); pages 479 – 483).

[2] Blind, D.; Kaes, H.; Weber, H.: Eigenschaften von betriebsbeanspruchten Schweißverbindungen zwischen den warmfesten Stählen X20CrMoV12-1 und 10CrMo9-10; VGB-Werkstofftagung "Werkstoffe und Schweißtechnik im Kraftwerk"; Essen (1985). (The qualities of operationally used weld connections between the heat resistant steels X20CrMoV12-1 and 10CrMo9-10; VGB materials conference: “Materials and welding technology in power plants”: Essen, Germany, 1985.)

[3] Bendick, W.; Niederhoff, K.; Haarmann, K.; Wellnitz, G.; Zschau, M.: 9 %-Chromstahl X10CrMoVNb9-1 – Ein Rohrleitungswerkstoff für Hochtemperaturkraftwerke. (The 9 % chrome steel X10CrMoVNb9-1 – a pipe material for high-temperature power plants.)