HEAT RESISTING STEELS OF THE NEW GENERATION AND EXAMPLES OF THEIR APPLICATION IN SUPERCRITICAL BOILERS DESIGNED FOR THE POLISH POWER PLANTS

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ABSTRACT

Short characteristics of the Polish power generation system. Basic characteristics of steels: T/P23, T24, T/P92, E911 and HCM12A and results of weldability examinations are given. Welding thermal cycles were simulated and the influence of $t_{8/5}$ cooling time on Charpy V impact strength, Vickers hardness and microstructure is presented in the form of graphs and CCT-diagrams. The susceptibility to reheat cracking has been also evaluated.
Tube and pipe joints were welded and mechanical properties of the welded test joints, Charpy V impact strength of weld metals and HAZ's were examined as well as the microstructure and hardness profiles. On the basis of the examination and test results proper welding conditions and PWHT parameters were selected which, can be applied to the newly built supercritical power boiler.

KEYWORDS

power generation, supercritical boiler, creep resisting steels, weldability, properties of welded joints

INTRODUCTION

The production of electrical energy in Poland is based on bituminous coal and lignite, which, with their rich deposits shall continue to be the main energy source for the next decades. Combustion of coal in power boilers is the source of emission into the atmosphere of a great number of pollutants such as CO_2, SO_2, NO_x and various kinds of particulate matter. European Parliament and European Council Directive 2001/80/EC "on the limitation of emissions of certain pollutants into the air from large combustion plants" sets acceptable limits on pollutants emission values [1]. The power and heat generating plants will have to reduce the emission of SO_2, NO_x and particulate matter in a strictly defined timetable [2, 3]. The reduction of SO_2 emission shown in Figure 1 [3] is especially important.

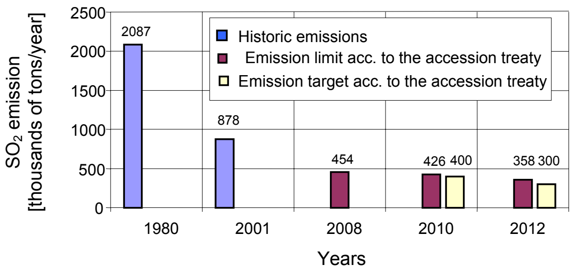

Fig. 1. SO_2 emission into the air from large combustion plants in Poland [3]

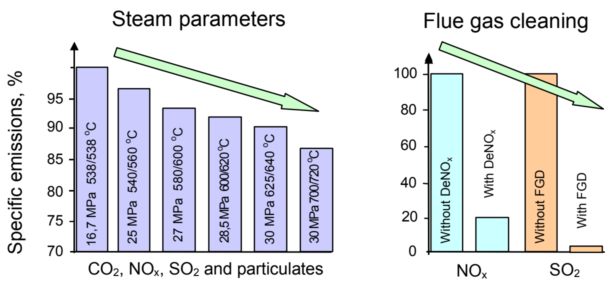

Fig. 2. Low emission levels achieved by high steam parameters and flue gas cleaning [4]

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Figure 1 demonstrates that SO_2 emission has to The supercritical operating parameters require new creep-resisting steels to be applied for the boiler be almost halved during six years, which is related with much higher costs than hitherto incurred [3]. The expenditure includes not only the costs of flue gas cleaning installations, but also the costs needed for the reconstruction of capacities, which have to be decommissioned even 10 years earlier than foreseen on the basis of their service life [3].
New power units operating at supercritical parameters have to be built in the near future. By the application of supercritical steam parameters the efficiency can be raised up to 45 %, depending on cooling conditions [4]. Better combustion conditions of fossil fuels lower the emission of pollutants into the air, which can be further decreased to low levels via flue gas cleaning – Figure 2 [4].
The supercritical operating parameters require new creep-resisting steels to be applied for the boiler and pipe systems. In order to prepare our power industry for the new task, weldability examinations have been performed at the Institute of Welding on selected Cr-W heat-resisting steels. RAFAKO Boiler Engineering Company and REMAK - Opole (Enterprise for the Modernisation of Power Installations) have executed tube/pipe test weld joints, followed by heat treatment and examination of weldment properties in order to select proper fabrication conditions. Some examination results performed in cooperation with the COST 522 research program [5] are presented in this paper.

1. BASIC CHARACTERISTCS OF HEAT - RESISTING STEELS

In the boiler section of a power unit the key elements are: water walls made of thin-walled tubes, steam superheaters and resuperheaters as well as live steam thick-walled pipes and headers. All these elements have to meet the requirements of good formability, weldability and ease of heat treatment. The used steels should be characterized by [7]:

- sufficient oxidation resistance to avoid extensive growth of oxide layers inside tubes and pipes which may cause an excessive temperature increase of their walls, leading to creep damage and/or spallation of hard oxide particles and erosion of turbine blades;
- adequate fire-side corrosion resistance to ensure as small as possible loss of material;
- mechanical properties which guarantee a long-lasting service at elevated temperatures (creep strength) taking also into consideration cyclic loading (resistance to low cycle thermal fatigue).

In table 1 the chemical composition of the heat-resisting steels of new generation is given and in Fig. 1 their creep strength, together with austenitic steels and nickel alloys is shown - for comparison.

Table 1. Chemical composition of ferritic heat-resisting steels (mass %)

Element	Steel grade				
	T/P23	T24)	E911	P92	HCM12A
C	0,04-0,10	0,05-0,10	0,09-0.13	0,07-0.13	0,07-0.13
Si	≤0,50	0,15-045	0,10- 0.50	≤0.50	≤0.50
Mn	0,10-0,60	0,30-070	0,30-0,60	0.30-0,60	≤0.70
Ni	-	-	0,10-0,40	≤0,40	≤0.50
Cu	-	-	-	-	0,30-1.70
Cr	1,90-2,60	2,20-2,60	8,50-9,50	8,50-9.50	10,0-12.5
Mo	0,05-0,30	0,90-1,10	0,90-1.10	0.30-0,60	0,25-0.60
W	1,45-1,75	-	0,90-1.10	1,50-2,00	1.50-2,50
V	0,20-0,30	0,20-0,30	0,18-0,25	0,15-0,25	0,15-0.30
Nb	0,02-0,08	-	0.06-0,10	0,04-0,09	0.04-0,10
N	≤0,030	≤0,01	0,05-0,09	0,03-0,07	0.06*)
B	0,0005-0,006	0,0015-0,007	0,0005-0,005	0.001-0,006	0.002*)

*) nominal chemical composition

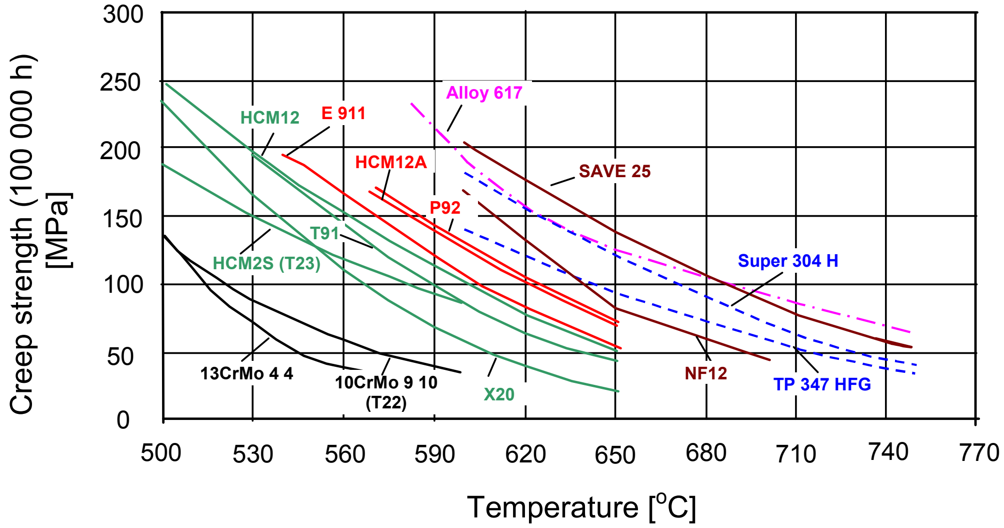

Fig. 1. Creep strength of heat-resisting materials (ferritic & austenitic steels and nickel alloys) used in the power generation industry

2. WELDABILITY CHARACTERISTICS

On steels listed in table 2 the following examinations and tests have been performed:

- By means of a special dilatometric device [9] transformation temperatures were determined on small cylindrical samples and CCT- diagrams for welding purposes (austenitizing temperature 1250 °C) were elaborated for selected steels.
- By using the thermal & stress-strain simulator, developed by Welding Institute, thermal cycles with a maximum temperature (T_{max}) of 1250 °C and cooling times $t_{8/5}$=6, 24, 60 and 300 s were simulated on samples and Charpy V notch toughness, Vickers hardness tests of simulated HAZ's were performed as well as metallographic examination of the microstructure.
- The susceptibility to reheat cracking was evaluated on samples with simulated HAZ's.

Table 2. Chemical composition of examined steels (mass %)

Steel		C	Si	Mn	P	S	Cr	Mo	W	V	B	N	Nb	Al	Other
T23 (HCM2S)	ϕ 63.5 x 9.8 mm	0.06	0.24	0.18	0.017	0.005	2.18	0.07	1.50	0.25	0.0055	0.007	0.04	0.003	
P23	ϕ 219 x 30 mm	0.07	0.28	0.54	0.008	0.004	2.08	0.08	1.65	0.22	0.0020	0.011	0.03	0.018	Ti - 0,07
T24	120 x 12 mm	0,11	0,31	0,53	0,013	0,013	2,43	1,00	-	0,25	0,010	-	-	0,010	
T92	ϕ 51.0 x 7.0 mm	0.09	0.22	0.45	0.017	0.002	8.81	0.45	1.64	0.23	0.004	0.042	0.06	0.017	
P92	ϕ 219 x 20 mm	0.11	0.21	0.43	0.013	0.006	8.93	0.49	1.65	0.19	0.005	0.055	0.05	0.008	
E911	ϕ 405 x 60 mm	0.12	0.17	0.47	0.016	0.003	8.62	0.94	0.93	0.20	0.0018	0.067	0.08	0.007	Ni - 0,23
HCM12A	ϕ 38 x 6,3 mm	0,10	0,27	0,58	0,017	0,002	12,10	0,25	1,84	0,19	-	-	0,09	-	Cu - 0.85 Ni - 0.35
HCM12A	ϕ 355 x 45 mm	0.13	0.31	0.60	0.014	0.001	10.65	0.35	1.92	0.22	-	-	0.06	-	Cu - 0.94 Ni - 0.35

2.1. CCT – diagrams and properties of simulated HAZ's

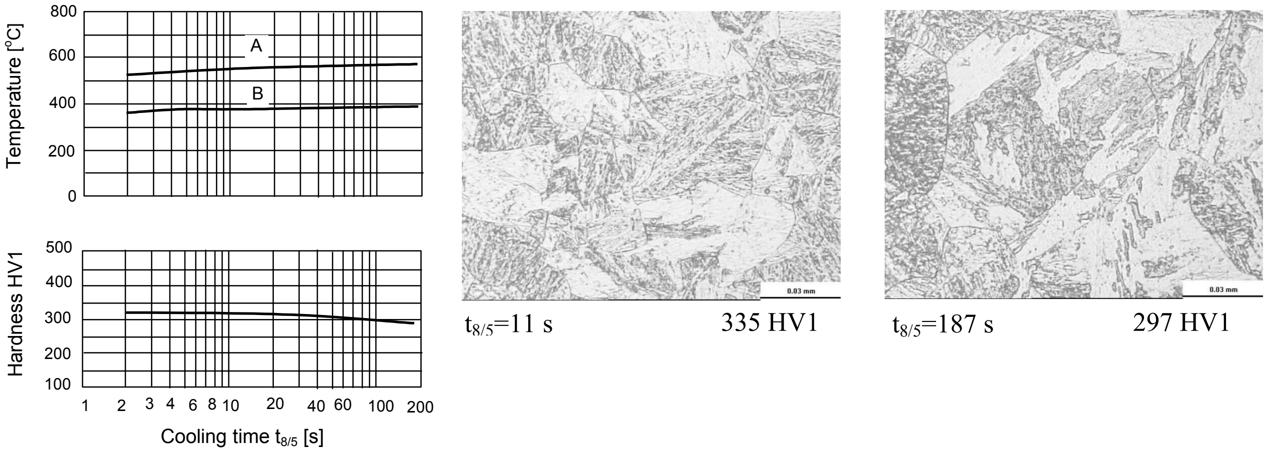

Fig. 2. CCT – diagram for T23 steel

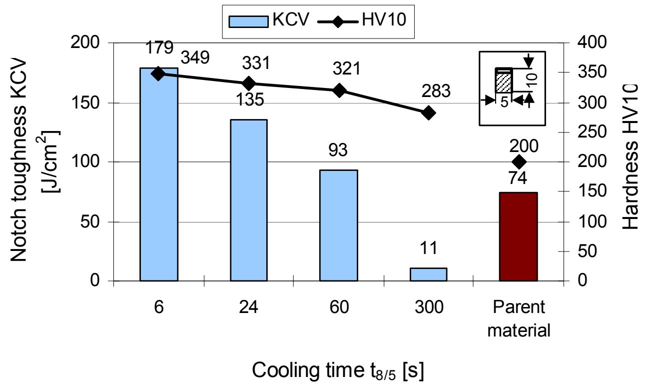

Fig. 3. Notch toughness KCV and hardness HV10 of simulated HAZ's for various cooling times of T23 steel. Maximum temperature of welding thermal cycles T_{max} = 1250 °C

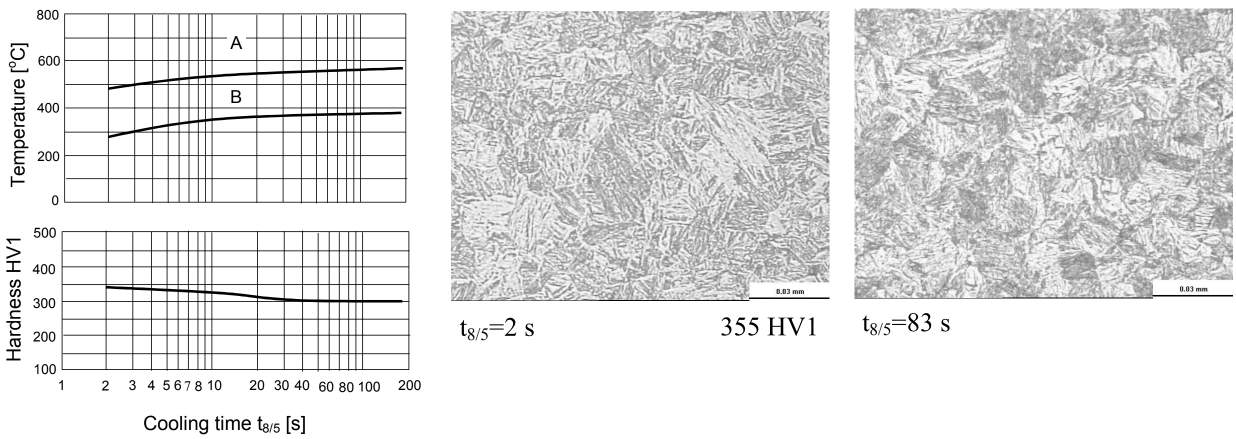

Fig. 4. CCT – diagram for T24 steel

As can be seen from CCT – diagrams (Fig. 2 and 4) during welding of the T23 and T24 steels bainitic microstructures will be formed in the heat affected zone (HAZ) with the hardness not exceeding 350 HV. It means that for lower wall thicknesses preheating will not be necessary and also post-weld heat treatment (PWHT) of welded joints, as the simulated HAZ has enough high impact strength (Fig. 3).

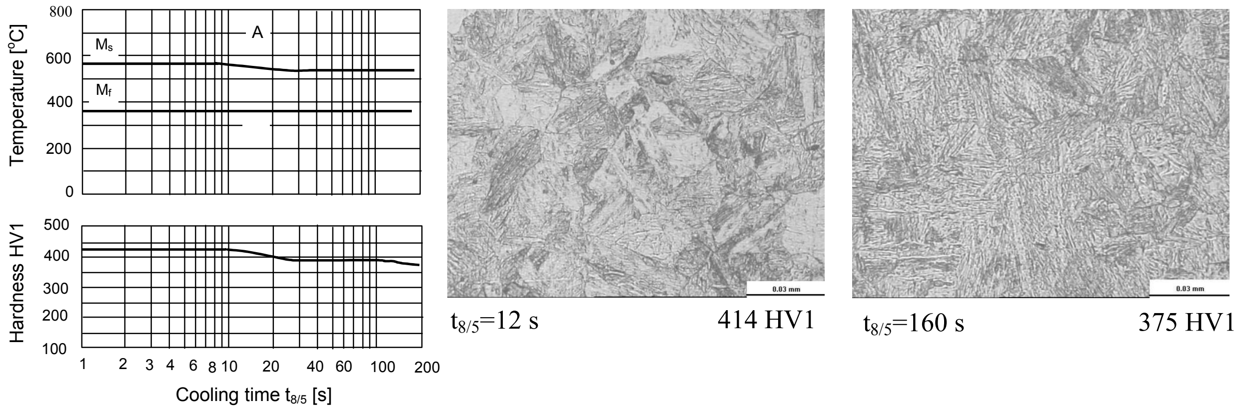

Fig. 5. CCT – diagram for T92 steel

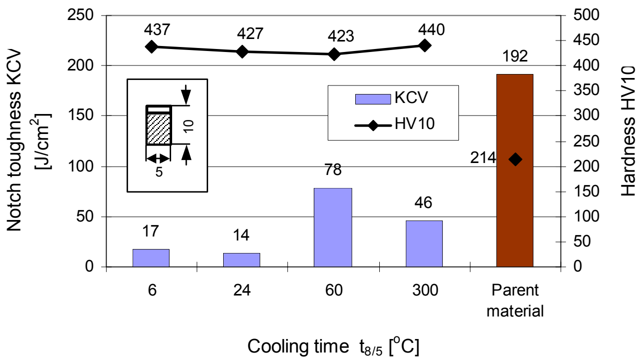

Fig. 6. Notch toughness KCV and hardness HV10 of simulated HAZ's for various cooling times of T92 steel. Maximum temperature of welding thermal cycles T_{max} = 1250 °C

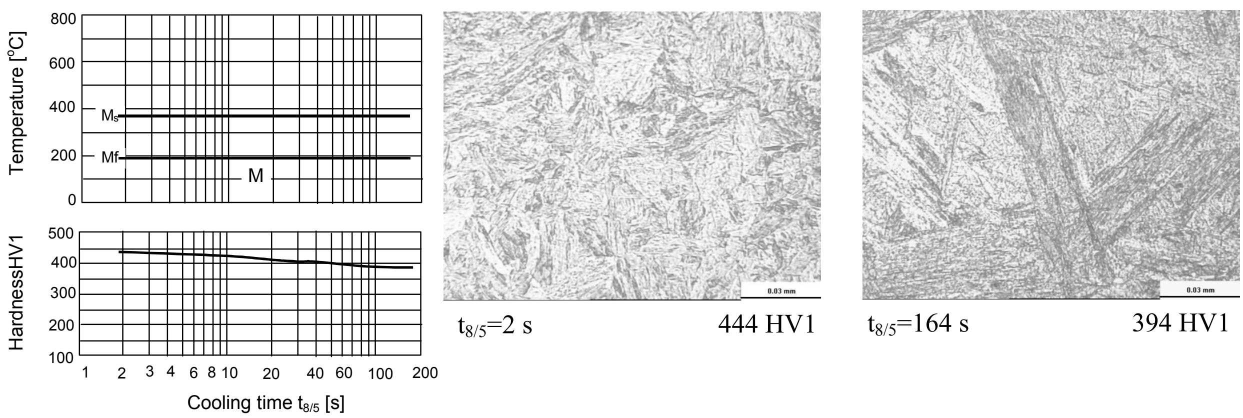

Fig. 7. CCT – diagram for E911 steel

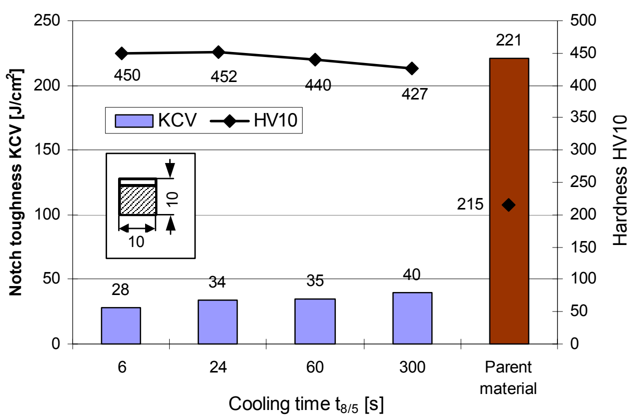

Fig. 8. Notch toughness KCV and hardness HV10 of simulated HAZ's for various cooling times of E911 steel. Maximum temperature of welding thermal cycles T_{max} = 1250 °C

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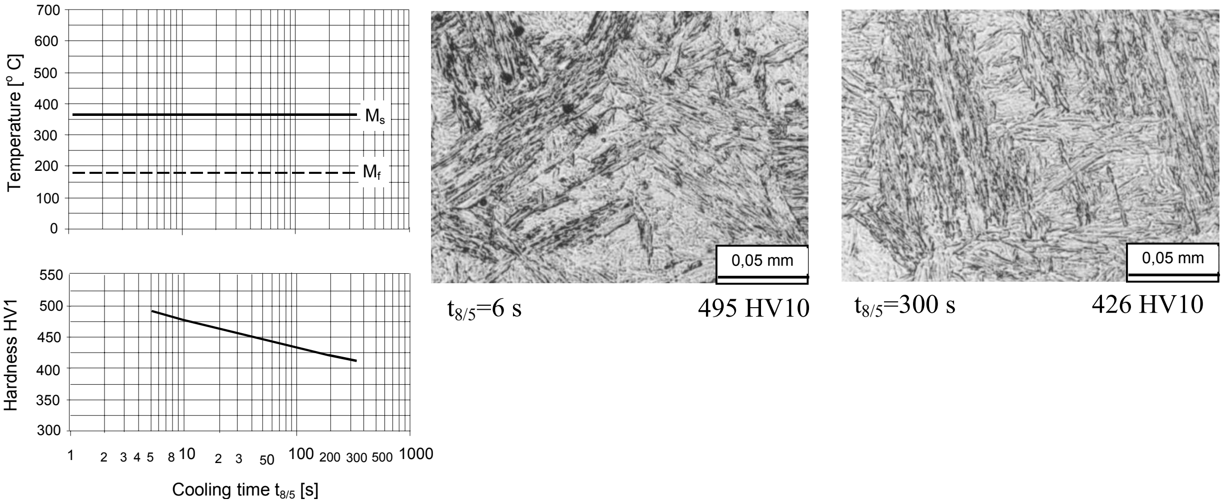

Fig. 9. CCT – diagram for HCM12A steel

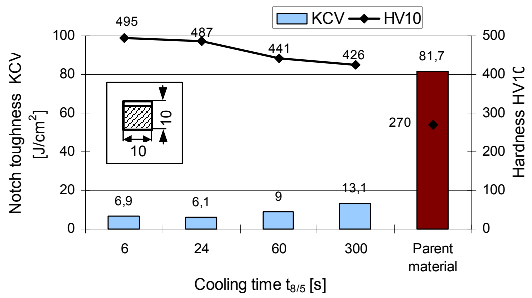

Fig. 10. Notch toughness KCV and hardness HV10 of simulated HAZ's for various cooling times of HCM12A steel. Maximum temperature of welding thermal cycles T_{max} = 1250 ^oC

Steels T/P92, E911 and HCM12A with a higher chromium content (8,5-12,5 % - see table 1) are of the martensitic type, and the CCT – diagrams (Figures 5, 7 and 9) show that martensite will be the transformation product in the HAZ during welding in the whole range of $t_{8/5}$ cooling times. For short cooling times the maximum HAZ hardness can be as high as 440 HV for P92 and E911 steels and 495 HV – for the HCM12A steel with the highest Cr content. The impact strength of the simulated HAZ's is much lower than that of the parent material in the quenched and tempered condition (Figures 6, 8 and 10). For that reason, the steels have to be preheated before welding to avoid cold cracking in the HAZ and weld metal. A post weld heat treatment is also needed for all thicknesses of parent material to temper the hard martensite microstructure and to improve the brittle fracture resistance by rising the impact strength of the welded joint.

2.2. Susceptibility to reheat cracking

Susceptibility to reheat cracking of welded joints has been evaluated using the method described in publication [10]. Samples (Figure 11) were subject to simulated thermal cycles with a maximum temperature of 1250 ^oC and cooling times $t_{8/5}$=6 s, 60 s and 600 s and tensile tested at temperatures within the range of 400–850 ^oC after soaking during 30 minutes. The strain rate was 0.5 mm/min. The measure of susceptibility to reheat cracking is the reduction of area (contraction) Z. A steel with Z > 20 % is considered as not susceptible to reheat cracking. Test results for steels T23, P92, E911 and HCM12A are presented in Figure 12.

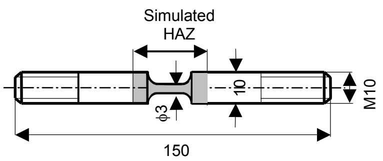

Fig. 11. Sample used for reheat cracking testing

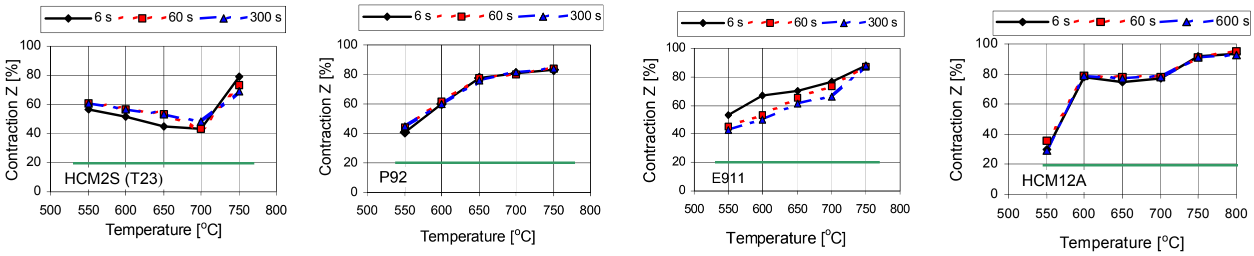

Fig. 12. Examination results of reheat cracking susceptibility of T23, P92, E911 and HCM12A steels

The test results presented in Fig. 12 confirm the resistance of all examined steels to reheat cracking.

3. WELDED JOINTS AND THEIR PROPERTIES

3.1. P23 steel pipe (ϕ 219 x 30 mm)

The test joint has been welded in the fixed vertical position (PC) on a pipe with the chemical composition given in Table 2. For the TIG welded root pass the Union ICr2WV wire (ϕ 2,4 mm) was used and Cr2WV covered electrodes (ϕ 2,5 mm and 3,2 mm), for the filling and cap layers. The preheating temperature was 150 °C and the interpass temperature did not exceed 250 °C
From the welded test joint a small segment was cut out to perform metallographic examination and impact tests in the “as welded” conditions. The remaining part of the welded pipe joint was heat treated at 740 °C for 2 hours in an electric resistance furnace. Mechanical tests, metallographic examinations and hardness measurements were carried out.

The cross-weld tensile tested specimens ruptured in the parent material at a tensile strength R_m=618 MPa, which is higher than the minimum value specified for the P23 steel (510 MPa). The side-bend test completed acc. to PN-EN 910 by using a 75 mm plunger (d=4t), to reach the 130 ° bend angle, shows good plastic properties of the welded joint. Notch toughness tests have been performed acc. to PN-EN 875 on Charpy V specimens with notches machined in the parent material, central part of the weld and in the HAZ (≈ 1 mm from the fusion line). Test results are presented in Figure 13. Macrostructure of the welded joint without PWHT and hardness distribution is presented in Fig. 14 and characteristic microstructures of the welded joint without and after PWHT are shown in Fig. 15.

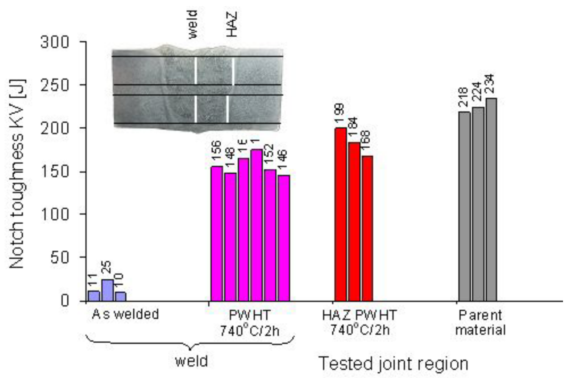

Fig. 13. Notch toughness KV of the P23 pipe welded joint

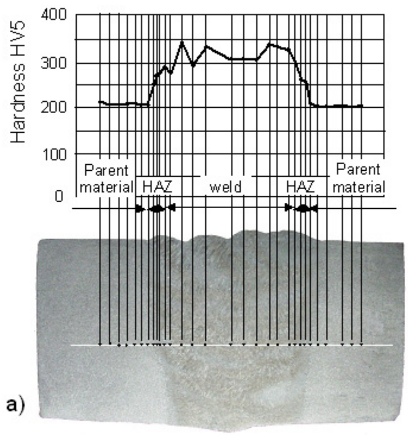

Fig. 14. Hardness profile of the P23 welded pipe welded joint without PWHT

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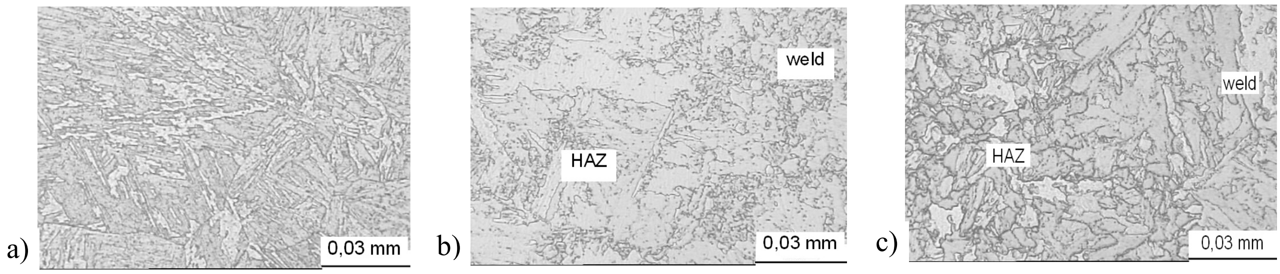


Parent material. Tempered bainite and martensite

Transition zone without PWHT. Bainite with carbides

Transition zone after PWHT (740 °C/2h). Tempered bainite

Fig. 15. Microstructures of the P23 pipe welded joints

3.2. T92 steel tube (ϕ 51 x 7,0 mm)

The T92 steel tube was welded by the TIG process (pulsed arc) in the fixed position (horizontal and vertical tube axis), using P92-IG Böhler wire ϕ 2,4 mm. The preheating temperature was 210-250°C, the interpass temperature did not exceed 350°C and the welding parameters were: 120/80-125/100 A, 14 V. The joints were post weld heat treated at 760 °C for 1,5 hour.
After radiographic inspection, which did not reveal unacceptable imperfections, metallographic examinations, hardness and mechanical tests were performed on the welded joints. The tensile strength was in the range of 655-695 MPa, which is higher than the minimum value 620 MPa required for the T92 steel. All specimens ruptured in the HAZ. In the bend test all specimens reached the bend angle of 180 °.
Notch toughness tests have been performed according to PN-EN 10045-1 on 10,0 x 5,0 mm Charpy V specimens. In Fig. 16 test results for joints welded in the fixed vertical (a) and horizontal (b) position are presented.
Vickers hardness was measured on samples taken from joints in the as welded condition and after PWHT. The HV5 hardness distribution is shown in Figure 17.

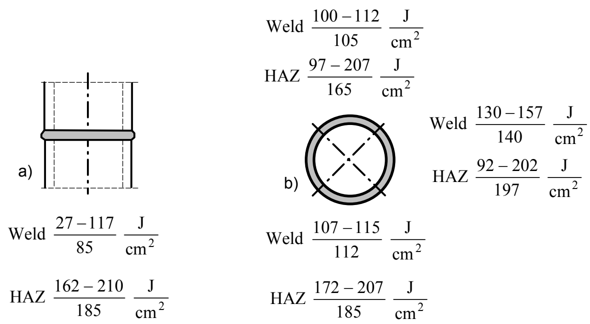


Fig. 16. Notch toughness KCV (Charpy V specimen 10,0 x 5,0 mm) of T92 tubes welded in the fixed vertical (a) and horizontal (b) position (numerator: range of measured values, denominator: mean value)

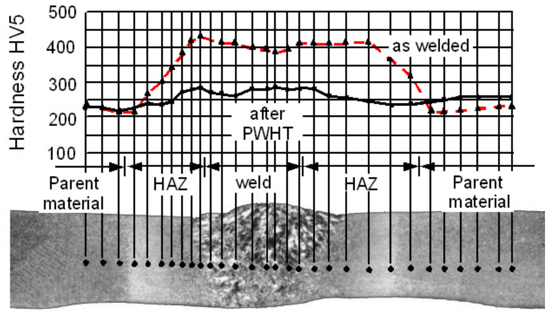


Fig. 17. Hardness distribution in the T92 steel welded joints, as welded and after PWHT - 760°C/1,5h

3.3 P92 steel pipe (ϕ 219 x 20 mm)

The root pass was TIG welded with Böhler P2-IG wire (ϕ 2,4 mm), for the filling passes FOX P92 stick electrodes (ϕ 2,5 mm and 3,2 mm) were used. Test joints were welded in the fixed horizontal (PF) and vertical (PC) position. The preheating temperature was in the range of 200-300°C with the interpass temperature not exceeding 350°C. After welding the joints were stress relieved at 760°C for 3 hours.
Tensile test specimens machined from the welded joints ruptured at the parent material at the tensile strength R_m in the range of 697-711 MPa, which is higher than the minimum R_m value (620 MPa) required for the P92 steel. In the side bend test all samples reached the bend angle of 180°.
Notch toughness tests have been performed according to PN-EN 875 on Charpy V specimens. In Figure 18 test results for joints welded in the fixed vertical (a) and horizontal (b) position are presented.
Results of macroscopic examination and Vickers hardness test are shown in Figure 19. Microstructure records of the parent material, HAZ and weld metal are presented in Figure 20.

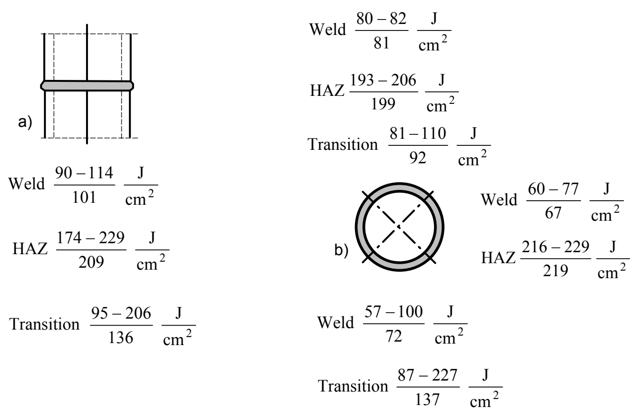


Fig. 18. Notch toughness KCV (Charpy V specimen 10,0 x 10,0 mm) of P92 pipes welded in the fixed vertical (a) and horizontal (b) position (numerator: range of measured values, denominator: mean value)

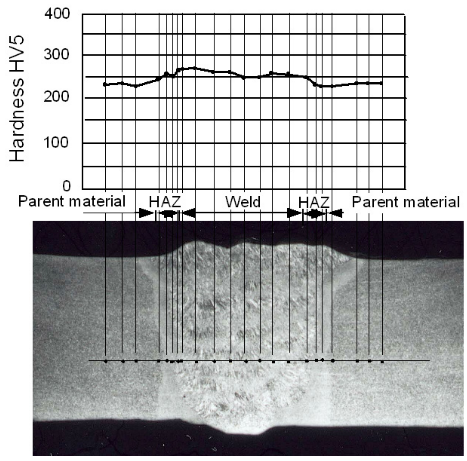
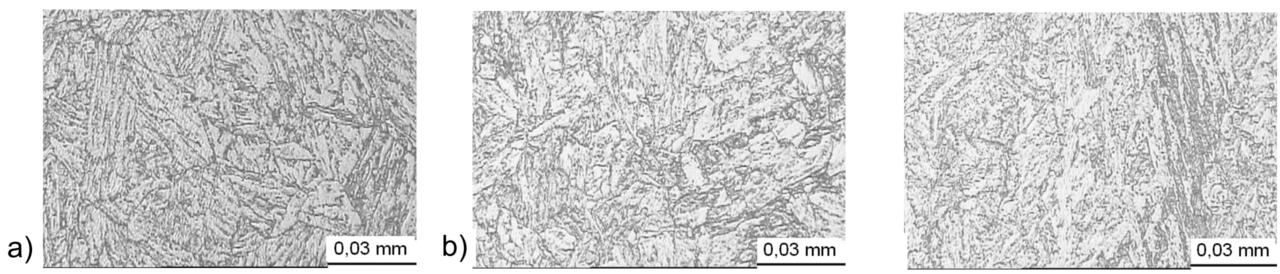


Fig. 19. Macrostructure of P92 joint welded in the fixed horizontal position (PF) and HV5 hardness distribution



Parent material
Tempered martensite, 240 HV5

HAZ
Tempered martensite, 275 HV5

Weld
Tempered martensite, 250 HV5

Fig, 20. Microstructures of the P92 joint welded in the fixed horizontal (PF) position (overhead segment), $FeCl_3$ etched.

3.4. E911 steel pipe (ϕ 405 x 60 mm)

Two butt joints have been welded on pipes in the fixed positions with horizontal and vertical pipe axis. The following Böhler fillers were used: C9 MVW-IG wire (ϕ 2,4 mm) - for the root pass TIG welding, and FOX C9 MVW stick electrodes (ϕ2,5 and 3,2 mm) - for the filling passes. The heat input did not exceed 20 kJ/cm. The welded joints were preheated to a temperature of 200 °C, the interpass temperature was maintained below 300 °C. After welding the joints were stress relieved at the temperature of 760 °C during 3 hours.
After positive results of ultrasonic testing, the following mechanical tests and examinations have been performed on the pipe joint welded in the horizontal fixed position:

- transverse tensile tests,
- side bend tests,
- impact tests on specimens located at triple depth of wall thickness with Charpy V notches machined at the center of weld metal, at the fusion boundary and at the HAZ (2 mm from fusion boundary),
- macro- and micro-examinations,
- hardness measurements on joint cross section.

All transverse tensile tests ruptured at the parent material and the tensile strength (R_m=686÷706 MPa) was higher than the minimum value required for the E911 steel (620 MPa). All side bend test results were positive. The impact absorbed energy for the tested regions of the pipe butt joint is given in Table 3.
The macrostructure of the welded joint is shown in Figure 21. Results of HV10 hardness measurements are listed in Table 4.

Table. 3. Impact absorbed energy for the E911 welded pipe butt joint

Welding position on the joint circumference	Impact absorbed energy [J][1)]		
	Weld metal	Fusion boundary	HAZ (2 mm)
Horizontal - PA	$\frac{38-55}{49,1}$	$\frac{64-188}{125}$	$\frac{139-163}{150}$
Vertical - PB	$\frac{39-56}{44,3}$	$\frac{46-200}{116}$	
Overhead - PE	$\frac{36-65}{52,1}$	$\frac{47-191}{142}$	

[1)] numerator: range of measured values, denominator: mean value

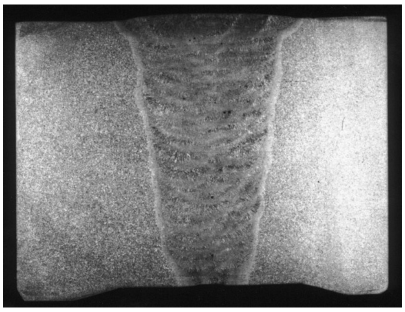
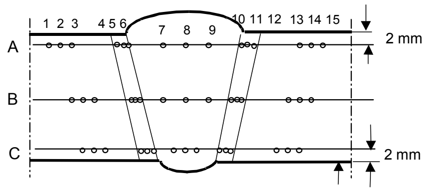


Fig. 21. Macrostructure of the E911 steel pipe joint welded in the fixed position (pipe axis horizontal). Quality level B acc. to PN- EN 25817

Table. 4. Hardness test results of welded E911 pipe joints

Welded joint	Line	Hardness HV10														
		Parent material			HAZ			Weld			HAZ			Parent material		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	A	201	201	202	239	265	262	250	241	247	248	225	207	209	207	210
	B	207	206	205	193	214	231	258	246	245	246	245	239	210	211	210
	C	197	200	195	241	265	279	271	273	283	276	265	241	207	208	208
	A	221	217	221	233	253	265	261	244	251	226	217	208	206	205	207
	B	221	222	221	216	222	233	270	268	272	236	211	209	213	215	212
	C	212	212	211	258	280	297	281	283	272	269	272	230	211	207	210



3.5 HCM12A steel tube and pipe joints

The tube joints ϕ 38 x 6.3 mm were TIG welded using T-HCM12A ϕ 1.6 mm Sumitomo wire with a preheating temperature of 250 ^{o}C. For welding ϕ 355 x 45 mm pipe joints the same wire was used for the root pass (TIG) and Sumitomo stick electrodes HCM12A (ϕ 2.4 and ϕ 4.0 mm) – for filling passes. Welded joints were heat treated for 5 h at the temperature of 740^{o}C - tubes and 760^{o}C - pipe. At the tensile test of tube welded joints the specimens ruptured in the parent material (R_m=772 MPa). Bend tests showed good plastic properties (130 ^{o}, plunger ϕ 20 mm). Results of Charpy V notch toughness tests (specimens 10.0 x 5.0 mm) were as follows: 94 J/cm^2 – parent material, 90 J/cm^2 – weld metal, 91 J/cm^2 – HAZ. Macrostructure of the pipe welded joint is presented in Fig. 22 and microstructures of the tube joint – in Figure 23.

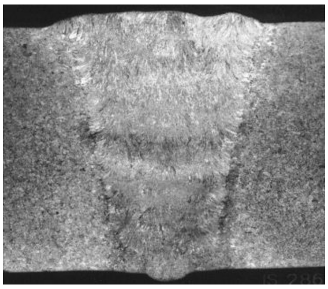
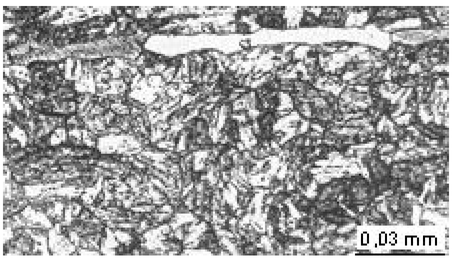
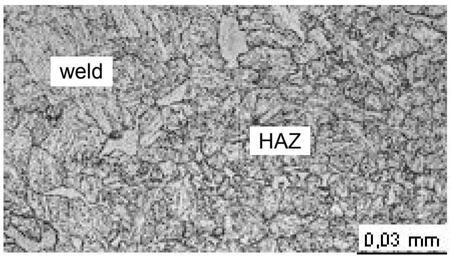


Fig. 22 Macrostructure of HCM12A steel pipe welded joint



235 HV10

Parent material.
Tempered martensite + delta ferrite



max. 270 HV10

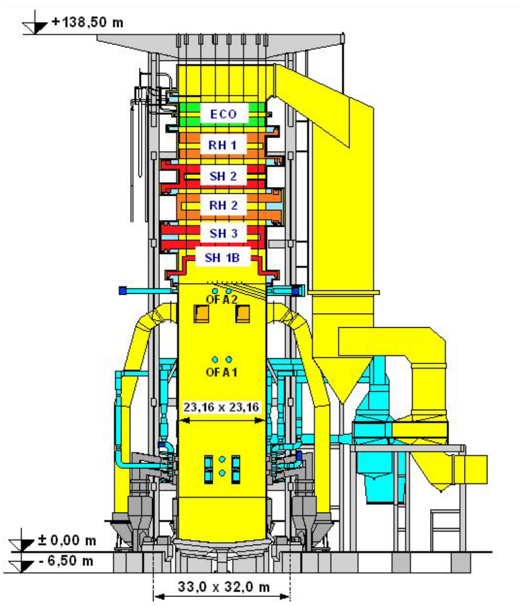
Transition zone.
Weld - tempered martensite + carbides
HAZ - tempered martensite + delta ferrite

Fig. 23. Microstructure of HCM12A steel tube welded joint. $FeCl_3$ etched

4. SUPERCRITICAL BOILER FOR THE BEŁCHATÓW POWER PLANT

Around 80% of power generation potential installed in Polish power plants consists in RAFAKO made equipment. RAFAKO is also a leading European manufacturer of boiler elements, using all types of creep-resistant steel grades in fabrication of pressure parts.
Construction of new power generating units in Poland combined with a growing share of RAFAKO export to European Union countries have forced the supplier of boilers with supercritical parameters to implement the activities aiming at implementation of new generation creep-resistant steel grades for fabrication of membrane walls, coils and collectors of steam superheaters and resuperheaters. Mastering of processes of welding and heat treatment processes of creep-resistant steel with the addition of tungsten was based on RAFAKO S.A. experience from mid-Seventies, mainly in construction of boilers with the application of X20CrMoV12.1 steel.

The design of the supercritical 833 MW boiler is based on the experience of the European power industry and especially on the German ones, as far as the replacement of worked out lignite fired power units is concerned. The boiler is of a high efficiency of 95 % at the efficiency of the power unit 40-45 % and are equipped with desulphurization installations to reduce the SO_2 emission. The general scheme of the boiler and its parameters are presented in Figure 24.



BELCHATÓW PS, 833 MW Unit "A",
Brown coal

Steam parameters
output: 2302 / 2400 t/h
pressure: 26,6 / 27,4 MPa
preheat temperature: 554/582 °C

Supplier of product engineering :
ALSTOM Power Boiler
Delivery of power unit:
Consortium:
ALSTOM Power Boiler GmbH & RAFAKO S.A

Fig. 24. Supercritical boiler for the Bełchatów Power Plant and its parameters

For the water wall elements at the upper part of the combustion chamber the T24 steel will be used instead of the 15Mo3 steel which was applied in subcritical power boilers.
The subcritical operating parameters require new creep-resisting steels to be applied not only for the boiler's combustion chamber and also for superheater coils and collectors. In order to withstand the operating parameters, for the last stages of steam superheaters, apart from new generation martensitic steel, it is necessary to use austenitic X3CrNiMoN steel.

The outlet headers of the last superheater and resuperheater stages will be made of the martensitic E911 steel with tungsten addition.

5. SUMMARY AND CONCLUSIONS

CCT-diagrams for welding purposes developed for the tested steels (T23, T24, T92, E911 and HCM12A) and examination results of the simulated HAZ's (Figures 2-10) provide a tool for the anticipation of the microstructure, hardness and notch toughness in the HAZ of welded joints, and as the result their susceptibility to cold cracking. In T92, E911 and HCM12A steels with high chromium content (8,8-12,1 %Cr - Table 2), within the wide range of $t_{8/5}$ cooling times, austenite is transformed to martensite during welding, characterized by high hardness values exceeding 400 HV. The notch toughness of simulated HAZ's is much lower than that of the base material (see Figures 6, 8 and 10). Preheating is therefore needed and post-weld heat treatment, to temper the martensite microstructure and to improve the impact strength of the weld metal and HAZ.

In T/P23 and T24 steels, with lower chromium content (2,2–2,4 %Cr – Table 2), bainitic transformations take place and the hardness of the HAZ is lower (< 350 HV – Figures 2-4). Tubes with small wall thickness can be welded without preheating. In most cases post-weld heat treatment is not necessary, due to good brittle fracture resistance of the HAZ (see Figure 3).

High temperature tensile tests performed on simulated HAZ's have revealed, that the T23, T92, E911 and HCM12A steels are not susceptible to reheat cracking (Figure 12).

Tube and pipe joints (P23, T92, P92, E911 and HCM12A) are characterized by tensile strength not less than that of the base materials and good plasticity. The notch toughness of HAZ's is high and does not differ from the properties of the base material. Lower impact strength values were measured at the weld metal of (Figures 13, 16. 18 and Table 3), but they satisfy the requirements of the technical inspection authorities.

As the final conclusion, it can be stated that tube and pipe joints of the new martensitic (T/P92, E911, HCM12A) and bainitic (T/P23, T24) steels, welded with proper filler materials, according to proven welding and PWHT procedures, have good mechanical properties, satisfy the requirements for brittle fracture resistance and can find their application in new built supercritical boilers.

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