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CONSIDERATIONS REGARDING THE SCC TESTING OF OLT45.3K STEEL WELDS

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ABSTRACT

Stress corrosion cracking (SCC) is specific for active elements from the thermo-energetic industry that work at high temperature and pressure.

Welds made out of OLT45.3K steel were mount within a brittleness detector, on a thermal circuit.

The paper presents the obtained results following from the verification of the SCC specimen tested on specific circuits by visual examination, free bending testing, metallographic examination and hardness testing.

These results indicate that the stress corrosion cracking resistance for the weld made out of OLT45.3K steel is assured.

KEY WORDS:

OLT45.3K steel, SCC testing, corrosion spot, weld

1. Introduction

The stress corrosion cracking phenomenon (SCC) is specific to active elements in energetics, elements, which run under high pressure and temperature conditions. The OLT45.3K steel is non-alloyed heat resistant steel used in the fabrication of tubular parts of the energetic boilers.

The capacity of the boiler water to produce steel brittleness can be evaluated by an experimental method, which uses a brittleness detector mounted on the boiler element in the interested area.

The testing device (brittleness detector) is so conceived that it simultaneously and continuously reunites three brittle factors: fluid flows, the chemical composition of the water and the thermo-mechanical stress of the steels and welded joints. The quality indexes of the water in the boiler circuit and technological pipelines are added. The proposed testing method for experimentation has an accelerated character as compared with the actual brittleness process in installations by the fact that the most favourable conditions are created to produce cracks in the controlled area of the specimen, easy to be examined and of restrained area.

The method has a prospective character and is applied on specimens

made out of steels and welded joints in the boiler construction. The method consists in exposing in the corrosive environment a pre-tensioned by bending specimen having the radius on the tensile fibre four times its thickness at 15 degree angle.

The fluid has to be focused on an intensely tensioned metallic surface of at least 1000 times.

2. SCC testing on the OLT45.3K welded joints

Specimens are sampled from OLT45.3K+OLT45.3K similar welded joints made out of ϕ 168 x 8 mm pipes completed by the customer on the basis of welding specifications applied on execution and mounting. The temperature regime of these joints is maximum 500°C. The verification of the welded joints was performed on the basis of conditions regarding the homologation of welding procedures (PT ISCIR CR7-96). The longitudinal axes of circumferential welds are placed at 57 mm against the threaded end of the specimen. The tensile part of the specimen with pre-strained weld contains the characteristic areas and corresponds to the internal walls of the pipes to the welds roots, respectively.

The SCC specimens subjected to the specific working regime of the steam circuit "continuous purging" on the isometric heat circuit have been verified by:

- visual examination of characteristic areas;
- determination of the residual strain state;
- free bending testing;
- metallographical examinations and hardness testing in the cross section.

2.1. Visual examination of characteristic areas

The state and aspect of examined specimens performed the respecting of the specific conditions imposed by the testing procedures of similar welded joints and of the surveillance instructions. So, specimens have no solid substance depositions coming from the corrosive steam. The fluid acted on the tensile surface continuously by the initial and on going correct adjustment. The aspect of the specimens is presented in figure 1 and the details of the tested surfaces are presented in figure 2.





Figure 1. Specimen 6 Figure 2. Detail specimen 6 The aspect of the specimens (pre-tensioned before testing) subjected to SCC testing is represented in figure 3.



Figure 3. Specimen 6

All the examined surfaces presented no corrosion cracks on the areas subjected to testing. The predominant color of the tested specimens is grey to black and characterizes the effect of the solid substance in the corrosive fluid.

2.2. Free bending testing

The residual strains obtained by bending in the device are about 8%, corresponding to the 18° angle (figure 3).

To identify the eventually microcracks, the pre-strained specimens have been subjected to the free bending with a 30 mm diameter mandrel, representing a value of four times of the specimen thickness.

The final bending angles, the recorded forces and the corresponding movements of the mandrel are presented in table 1. No SCC brittle cracks were found in the free strain process on the mandrel. This result confirms that the working environment does not produce the brittleness of the base metal and of the welded joint, after a 30 days cycle.

			Table 1.
Mark	Angle	Force (N)	Movement (mm)
6	65 ⁰	6700	5
		8150	10
		9900	15

2.3. Metallographical examination

The macroscopic examination of the SCC specimens longitudinally sampled at the "6" sample subjected to the corrosive action of the overheated steam (figures 4 ... 7) evinced no corrosion cracks.





Figure 4. Sample 6.1-1 [Nital etched 10%]

Figure 5. Sample 6.1-2 [Nital etched 10%]





Figure 6. Sample 6.2-1 [Nital etched 10%] Figure 7. Sample 6. 2-2 [Nital etched 10%]

The microscopic examinations according to EN 1321 and SR ISO 643 were performed in the characteristic areas of the welded joints subjected to the corrosive action of the steam in the heat circuits.

The area subjected to the corrosive action was sectioned longitudinally by "the corrosion spot" obtaining two samples 6.1 and 6.2. Each sample present two faces "1" and "2".

 In the base metal (BM), the structures are ferrito-pearlitic granular, granulation of 8-9 points, according to SR ISO 643 (figures 8...11).



Figure 8. Sample 6.1-1 BM [Nital etched 3%, x100]







Figure 9. Sample 6.1-2 BM [Nital etched 3%, x100]



Figure 11. Sample 6. 2-2 BM [Nital etched 3%, x100]

No fabrication defects and corrosion cracks have been found in the examined areas of the base metal, the corrosion depth does not exceed the value of 0.09 mm.

 In the weld (WELD), the structures are dendritic pearlitic ferritic with elongated dendrites on the thermal flux direction and on the restrained areas acicular ferrite structures were developed, which do not exceed 2 points (W2), according to STAS 7626 (figures 12 ... 19)



Figure 12. Sample 6.1-1 WELD [Nital etched 3%, x100]



Figure 14. Sample 6.1-2 WELD [Nital etched 3%, x100]



Figure 16. Sample 6.2-1 WELD [Nital etched 3%, x 100]



Figure 18. Sample 6.2-2 WELD [Nital etched 3%, x 100]



Figure 13. Sample 6.1-1 WELD [Nital etched 3%, x500]



Figure 15. Sample 6.1-2 WELD [Nital etched 3%, x500]



Figure 17. Sample 6.2-1 WELD [Nital etched 3%, x 500]



Figure 19. Sample 6.2-2 WELD [Nital etched 3%, x 500]

The depth of "the corrosion spot" in the weld has minimum values of 0.40 mm for the 6.2-1 sample (figure 20) and of 0.38 mm for the 6.1-1 sample (figure 21).



Figure 20. Sample 6.2-1 WELD [Nital etched 3%, x 100]



Figure 21. Sample 6.1-1 WELD [Nital etched 3%, x 100]

In the examined welds were found no welding defects such as microcracks and corrosion microcracks type defects due to the corrosion phenomena of the steam. "The corrosion spot" was formed in the direct contact area steam - specimen where the most corroded areas appear, the other areas present reduced corrosion phenomena, the corrosion depths varies between 0.03 and 0.11 mm.

 In the heat affected zones (HAZ₁, HAZ₂), the structure is pearlite ferritic granular with acicular ferrite and the granulation 4-6 points, according to SR ISO 643 (figure 22 ... 29).



Figure 22. Sample 6.1-1 HAZ [Nital etched 3%, x 100]



Figure 24. Sample 6.1-2 HAZ [Nital etched 3%, x 100]



Figure 23. Sample 6.1-1 HAZ [Nital etched 3%, x 500]



Figure 25. Sample 6.1-2 HAZ [Nital etched 3%, x 500]



Figure 26. Sample 6.2-1 HAZ [Nital etched 3%, x 100]



Figure 28. Sample 6.2-2 HAZ [Nital etched 3%, x 100]



Figure 27. Sample 6.2-1 HAZ [Nital etched 3%, x 500]



Figure 29. Sample 6.2-2 HAZ [Nital etched 3%, x 500]

The examined areas had no microcracks, they presented in the contact areas steam - metal different corrosion depths in the range 0.07 and 0.12 mm.

2.4. Hardness testing

The Vickers (HV5) hardness test was performed according to STAS 492/1-85. The distribution scheme of the hardness indentations is according to figure 30, and the results of the tests are included in table 2.

The relative justice error "E" is \pm 3%.

The relative fidelity error "E" is $\pm 4\%$.





	Investigated	Tensile fibre (TF)		Neutral fibre(NF)				
Sample						compressed fibre(CF)		
mark	zone	HV5	HB		HB	HV5	HB	
		178	169	165	157	170	161	
	BM_1	175	166	166	158	175	166	
		177	168	167	159	178	169	
	HAZ ₁	241	229	238	226	228	217	
		236	224	230	219	240	228	
	-	225	214	232	220	225	214	
6 1-1	WELD	230	224	230	219	219	208	
0.1 1		223	210	220	209	217	200	
		244	232	235	223	226	215	
	HAZ ₂	242	230	237	225	228	217	
		236	224	235	223	224	232	
		172	163	160	152	172	163	
	BM ₂	170	161	162	154	170	161	
		1/6	167	164	156	170	161	
	RM.	168	160	166	158	1/2	163	
		108	160	164	154	170	168	
		247	235	272	211	229	218	
	HAZ ₁	246	234	223	212	239	227	
	1 ·	237	225	231	219	228	217	
		235	223	230	219	232	220	
6.1-2	WELD	237	225	229	218	227	216	
		230	219	235	223	228	217	
		244	232	231	219	241	229	
	TAZ2	248	230	237	225	240	228	
		166	158	160	152	160	152	
	BM ₂	172	163	150	143	160	152	
	2	165	157	149	142	162	154	
		177	168	160	152	170	161	
	BM_1	171	162	159	151	172	163	
6.2-1		182	173	160	152	177	168	
0.2 1		250	238	226	215	229	218	
	HAZ ₁	249	237	225	214	221	210	
		240	228	220	209	219	208	
Samala	_	Tensile fibre (TF)		Neutral fibre (NF)		Compressed fibre (CF)		
Sample	Invoctigated	rensile	fibre (TF)	Neutral	fibre (NF)	Compresse	d fibre (CF)	
mark	Investigated zone	Tensile	fibre (TF)	Neutral 1 Ha	fibre (NF) ardness	Compresse	d fibre (CF)	
mark	Investigated zone	HV5	fibre (TF)	Neutral 1 Ha HV5	fibre (NF) ardness HB	Compresse HV5	d fibre (CF)	
mark	Investigated zone	HV5 238	fibre (TF) HB 226	Neutral 1 Ha HV5 220	fibre (NF) ardness HB 209	Compresse HV5 229	HB 218	
mark	Investigated zone WELD	HV5 238 241	fibre (TF) HB 226 229	Neutral f HV5 220 225 225	fibre (NF) ardness HB 209 214	Compresse HV5 229 240	HB 218 228	
mark	Investigated zone WELD	HV5 238 241 240 241	HB 226 229 228 229	Neutral f HV5 220 225 223 210	fibre (NF) ardness HB 209 214 209 209	Compresse HV5 229 240 242 237	HB 218 228 230 225	
6.2-1	Investigated zone WELD ZIT:	HV5 238 241 240 241 244	HB 226 229 228 229 232	Neutral f HV5 220 225 223 219 226	fibre (NF) ardness HB 209 214 209 208 215	Compresse HV5 229 240 242 237 242	HB 218 228 230 225 230	
6.2-1	Investigated zone WELD ZIT2	HV5 238 241 240 241 241 244 239	HB 226 229 228 229 228 229 228 229 232 277	Neutral 1 HV5 220 225 223 219 226 235	Fibre (NF) ardness HB 209 214 209 208 215 223	Compresse HV5 229 240 242 237 242 242 240	HB 218 228 230 225 230 225 230 228	
6.2-1	Investigated zone WELD ZIT2	HV5 238 241 240 241 244 239 170	HB 226 229 228 229 232 227 161	Neutral 1 HV5 220 225 223 219 226 235 156	Fibre (NF) ardness HB 209 214 209 214 209 215 223 148	Compresse HV5 229 240 242 237 242 242 240 166	HB 218 228 230 225 230 225 230 228 158	
6.2-1	Investigated zone WELD ZIT2 MB2	HV5 238 241 240 241 244 239 170 168	HB 226 229 228 229 232 227 161 160	Neutral 1 HV5 220 225 223 219 226 235 156 150	Fibre (NF) ardness HB 209 214 209 218 215 223 148 143	Compresse HV5 229 240 242 237 242 242 240 166 169	HB 218 228 230 225 230 228 158 161	
mark 6.2-1	Investigated zone WELD ZIT2 MB2	HV5 238 241 240 241 244 239 170 168 168	HB 226 229 228 229 232 227 161 160	Neutral 1 HV5 220 225 223 219 226 235 156 150 162	Fibre (NF) ardness HB 209 214 209 218 209 148 143 154	Compresse HV5 229 240 242 237 242 240 166 169 170	HB 218 228 230 225 230 228 158 161 162	
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mark 6.2-1	Investigated zone WELD ZIT ₂ MB ₂ MB ₁	HV5 238 241 240 241 243 170 168 168 175 178	HB 226 229 228 229 232 227 161 160 166 169	Neutral 1 HV5 220 225 223 219 226 235 156 150 162 160 162	Fibre (NF) ardness HB 209 214 209 208 215 223 148 143 154 152 154	Compresse HV5 229 240 242 237 242 240 166 169 170 171 170	HB 218 228 230 225 230 161 162 161 162 161	
mark 6.2-1	Investigated zone WELD ZIT2 MB2 MB1	HV5 238 241 240 241 243 170 168 168 175 178 171	HB 226 229 228 229 232 227 161 160 160 160 160 160 162	Neutral 1 HV5 220 225 223 219 226 235 156 150 162 162 162 225	Fibre (NF) ardness HB 209 214 209 215 223 148 154 152 154 154 209	Compresse HV5 229 240 242 237 242 240 166 169 170 171 170 177 220	HB 218 228 230 225 230 228 158 161 162 161 162 230	
6.2-1	Investigated zone WELD ZIT ₂ MB ₂ MB ₁ 7IT.	HV5 238 241 240 241 244 239 170 168 168 168 168 168 175 178 171 237 242	HB 226 229 228 229 232 227 161 160 166 169 162 225	Neutral 1 HV5 220 225 223 219 226 235 156 150 162 166 230 225	fibre (NF) ardness HB 209 214 209 215 223 148 154 152 154 152 215	Compresse HV5 229 240 242 237 242 240 166 169 170 171 170 177 230 222	HB 218 228 230 225 230 228 158 161 162 161 162 161 230	
6.2-1	Investigated zone WELD ZIT ₂ MB ₂ MB ₁ ZIT ₁	HV5 238 241 240 241 244 239 170 168 168 168 168 175 178 171 237 242 240	HB 226 229 228 229 232 227 161 160 166 169 162 225 230 277	Neutral 1 HV5 220 225 223 219 226 235 156 150 162 160 162 230 220 225	fibre (NF) ardness HB 209 214 209 218 143 154 152 154 152 154 209 214	Compresse HV5 229 240 242 237 242 240 166 169 170 171 170 177 230 232 235	HB 218 228 230 225 230 228 161 162 161 162 161 229 230	
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6.2-1	Investigated zone WELD ZIT2 MB2 MB1 ZIT1 SUD	HV5 238 241 240 241 240 170 168 168 175 178 171 237 242 240 235	HB 226 229 228 229 232 227 161 160 166 169 162 225 230 225 230 228 228 223	Neutral 1 HV5 220 225 223 219 226 235 156 150 162 160 230 220 235	fibre (NF) ardness HB 209 214 209 208 215 223 148 143 154 152 154 158 219 209 214	Compresse HV5 229 240 242 237 242 240 166 169 170 171 170 177 230 232 235 245 240	HB 218 228 230 225 230 225 161 162 161 162 219 223 233 223	
6.2-1	Investigated zone WELD ZIT2 MB2 MB1 ZIT1 SUD	HV5 238 241 240 241 240 170 168 168 175 178 171 237 242 240 240 235 232	HB 226 229 228 229 232 227 161 160 166 169 162 225 230 225 230 228 223 223 223 223 220	Neutral 1 HV5 220 225 223 219 226 235 156 150 162 160 162 200 225 235 226 235 156 160 220 220 225 229 232 239	fibre (NF) ardness HB 209 214 209 218 215 223 148 143 154 152 154 158 219 209 214 223	Compresse HV5 229 240 242 237 242 240 166 169 170 171 170 177 230 232 235 245 240 242	HB 218 228 230 225 230 225 161 162 161 162 219 220 233 233 233 233 230	
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6.2-1	Investigated zone WELD ZIT2 MB2 MB1 ZIT1 SUD ZIT2	HV5 238 241 240 241 244 239 170 168 168 175 178 171 237 242 240 240 240 240 240 240 242 240 242 240 241	HB 226 229 228 229 232 27 161 160 166 162 225 230 228 2230 228 2230 228 220 230 228 230 230 231 220 231 220 232 230 233 230 234 171 166	Neutral 1 HV5 220 225 223 219 226 235 156 150 162 160 220 220 235 156 150 162 230 220 230 30	fibre (NF) ardness HB 209 214 209 218 215 223 148 143 154 152 154 219 209 214 215 223 148 143 154 152 124 219 220 219 220 219 158 158 158 219 220 219 158 162	Compresse HV5 229 240 242 237 242 240 166 169 170 171 170 177 230 232 235 245 240 242 245 240 242 245 240 242 245 240 242 245 240 242 245 240 242 245 240 247 237 237 237 237 237 237 240 242 240 166 169 170 171 170 237 237 242 240 242 240 242 240 242 240 242 240 242 240 242 240 242 240 242 240 242 240 242 240 240	HB 218 228 230 225 230 228 158 161 162 161 228 230 228 230 228 161 162 200 223 233 228 230 234 237 219 161 162	
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The \triangle HB estimator represents the local structural hardening of an area reported to another area, the hardening of the (TF) tensile and (CF) compressed area reported to the neutral area (NF). This estimator can be calculated by the relation:

Table 2

$$\Delta HB = \frac{HB_{max(TF,CF)} - HB_{min(NF)}}{HB_{min(NF)}} \cdot 100 \quad [\%]$$
(1)

When $\Delta HB > 0$ there appears a local structural hardening, and when $\Delta HB < 0$ there appears a local structural softening.

Table 3 gives the \triangle HB values calculated by relation (1).

_		-	Table 3.		
Sample	Evaluated	∆HB estimator [%]			
mark	zone	Tensile fibre (TF)	Compressed fibre (CF)		
	MB_1	7,80	7,64		
	ZIT_1	4,56	4,10		
6.1-1	SUD	4,67	1,40		
	ZIT ₂	4,03	4,03		
	MB ₂	9,86	5,84		
6.1-2	MB_1	5,84	8,44		
	ZIT_1	11,37	7,58		
	SUD	2,29	1,41		
	ZIT ₂	8,67	5,93		
	MB ₂	14,78	8,45		
	MB_1	14,56	11,25		
	ZIT_1	13,87	4,30		
6.2-1	SUD	9,56	10,66		
	ZIT ₂	11,53	10,57		
	MB ₂	12,58	13,28		
	MB_1	11,18	10,52		
	ZIT_1	10,04	6,69		
6.2-2	SUD	4,58	6,88		
	ZIT_2	6,84	8,21		
	MB_2	13,24	7,28		

On the basis of the determined ${\scriptstyle \Delta}\text{HB}$ estimator the following can be concluded:

- for welded samples 6.1-1 and 6.1-2 there appear local structural hardening on TF and CF between 1.40% for the 6.1-1 (WELD) sample and 14.78% for the 6.1-2 (BM₂) sample;
- for the welded samples 6.2-1 and 6.2-2 there appear, local structural hardening on TF and CF fibres, where the minimum value of the estimator is 4.3% for the 6.2-1 sample (HAZ₁) and the maximum one is 14.56% for the 6.2-1 sample (BM₁).

3. Conclusions

3.1. The OLT45.3K +OLT45.3K similar welded joint inestigated by the SCC testing has assured the stress corrosion cracking resistance on the live steam circuits.

3.2. In this way, it is confirmed that the steam produced in installations and which contains nitrides and other solid substances has no brittle effects in welded areas on the heat circuits of the installations under mechanical and thermal tension.

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