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ISTRAŽIVANJE MOGUĆNOSTI ZAVARIVANJA CEVI OD ČELIKA X10CrMoVNb9-1 PRIMENOM AUSTENITNOG DODATNOG MATERIJALA BEZ NAKNADNE TERMICKE OBRADE

INVESTIGATION OF THE POSSIBILITY OF DIRECT WELDING OF X10CrMoVNb9-1 STEEL TUBES WITH AUSTENITIC FILLER MATERIAL WITHOUT POST-WELD HEAT TREATMENT

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Rezime: Ideja za ovaj rad proizašla je iz praktičnog problema ko se pojavljuje prilikom zamene cevnih zmija međupregrejača sekundarne pare, izrađenih od čeličnih cevi oznake X10CrMoVNb9-1 i dimenzija 32x4mm. Naime, zavarivanje ovog materijala zahteva termičku obradu nakon zavarivanja. Zavarivanje montažnih spojeva između krajeva sabirnih cevi kolektora i krajeva cevi zmija, u uslovima ograničenog prostora, predstavlja poseban izazov zbog velikog broja takvih spojeva. Situacija je dodatno otežana činjenicom da redosled zavarivanja nije proizvoljan, već se mora strogo poštovati. U takvim uslovima, termička obrada svakog zavarenog spoja značajno komplikuje postupak montaže međupregrejača i znatno produžava vreme zastoja potrebno za završetak radova. Ovaj rad ispituje mogućnost izvođenja spojeva direktnim zavarivanjem, uz upotrebu austenitnog dodatnog materijala na bazi nikla, kako bi se izbegla termička obrada nakon zavarivanja, posebno imajući u vidu male prečnike i debljine zidova cevi koje čine zmije međupregrejača.

Ključne reči: Termička obrada nakon zavarivanja, dogrevač pare, dodatni materijal na bazi Ni, Thermanit Nicro 82, NIBAS 70/20-IG

Abstract: The idea for this paper was motivated by a practical problem encountered during the replacement of a boiler reheater coils made of X10CrMoVNb9-1 steel tubes with dimensions 32x4mm. Specifically, welding this material requires post-weld heat treatment (PWHT). Welding the site joints between the header tube ends and the coil tube ends, within a confined space, presents a particular challenge because there are to many. This is more demanding when the welding sequence is not arbitrary but must be strictly followed. Under these conditions, post-weld heat treatment of every welded joint significantly complicates the reheater assembly procedure, and substantially extends the downtime required for job completion. Therefore, the study examines whether the joint could be made via direct welding, using austenitic filler material based on Ni, to avoid post-weld heat treatment, especially considering the small diameter and wall thickness used in the coil tubes.

Key words: PWHT, X10CrMoVNb9-1, reheater, Ni based filler material, Thermanit Nicro 82, NIBAS 70/20-IG

1. INTRODUCTION

In modern high-efficiency power generation, boiler components operate under demanding thermal and mechanical stress. Superheater and reheater tubing systems represent the most thermally exposed zones of the steam generator, handling steam temperatures above 550°C and pressures exceeding 25 MPa [1]. Selecting an optimal material for these components is vital to ensuring long-term creep resistance, structural integrity, and resistance to high-temperature oxidation and steam-side scaling.

Among candidate materials, X10CrMoVNb9-1 (commonly designated as Grade 91) has established itself as the premier choice for high-temperature superheater and reheater tubing applications [2].

The alloy features a fully tempered martensitic structure stabilized by micro-alloying additions of vanadium (V) and niobium (Nb), which form fine MX-type carbonitrides that block dislocation movement and slow down creep deformation over long service times [3]. Steel X10CrMoVNb9-1 exhibits significantly higher allowable stress limits at temperatures up to 600°C–620°C compared to conventional low-alloy steels like 2.25Cr-1Mo (P22/T22).

Compared to austenitic stainless steels (such as 304H or 347H), Grade 91 offers lower thermal expansion coefficients and higher thermal conductivity. This minimizes thermal stresses during cyclic operation and reduces the risk of fatigue cracking. The high design strength allows for thinner tube walls. This reduces overall component weight, lowers fabrication and piping support costs, improves boiler heat-transfer efficiency, and reduces thermal gradient stresses across the tube wall [4].

A 9% chromium content provides adequate resistance against fireside corrosion and steam-side oxidation at operating temperatures up to 600°C [5].

Consequently, X10CrMoVNb9-1 bridges the gap between low-alloy ferritic/martensitic steels and expensive austenitic alloys, providing an optimal balance of mechanical performance, longevity, and cost-efficiency for critical boiler tubing systems.

Grade 91 derives its strength from a precise, delicate microstructure of tempered martensite reinforced by fine carbonitride precipitates (V, Nb). When subjected to the heat of welding, this microstructure is easily destroyed, leaving zero margin for error.

Post-Weld Heat Treatment (PWHT) is the most critical and narrow stage of welding X10CrMoVNb9-1. Because Grade 91 is a Creep Strength Enhanced Ferritic (CSEF) steel, its strength comes from a precise tempered martensitic matrix held together by fine vanadium/niobium carbonitride precipitates (V, Nb).

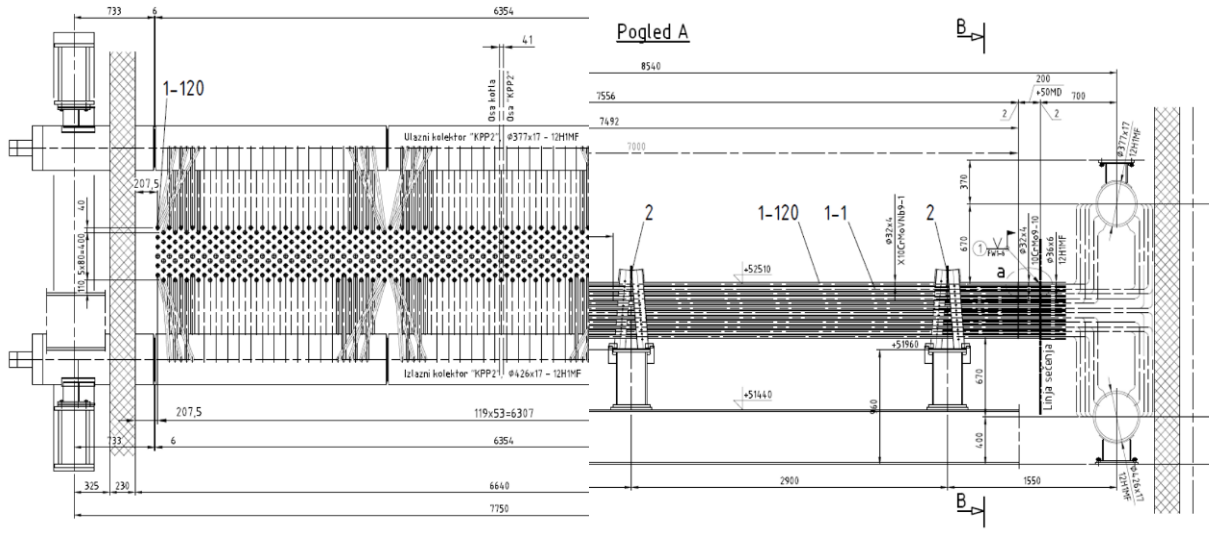


Fig.1: Reheater tubes arrangment

Fig.1 shows a case of a reheater reconstruction where only the tube coils are replaced, while the old headers remain unchanged. In this reheater (fig.2), the design of the tube coils is such that during replacement, on-site PWHT is virtually impossible due to the assembly sequence. Welding begins at the center of the headers and proceeds outwards, leaving the central sections inaccessible later.

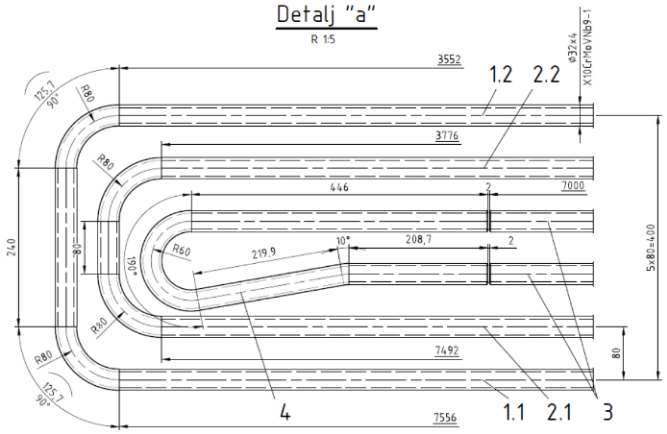


Fig.2: Tubes arrangment-three coils in one plane

For the reheater shown in fig.1 and 2, the tube coils are made of X10CrMoVNb9-1, whereas the headers connection tubes and the headers itself, are made of a dissimilar lower grade steel 10CrMo9-10, with a F+P+B microstructure.

In this case, the designer found an elegant solution by inserting a short tube (fig.3) of the same material-10CrMo9-10 as the header tubes. This allows the PWHT to be performed under controlled conditions in the workshop (fig.4) rather than on-site, which makes a huge difference in time and effort.

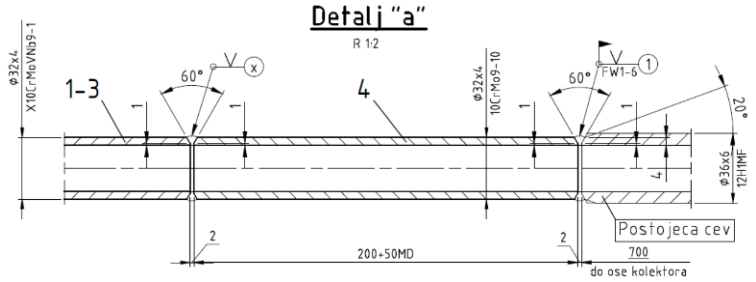


Fig.3: Solution for avoiding heat treatment during assembly by inserting dissimilar tube



Fig.4: PWHT of end tubes of boiler reheater

Finally, only the field welds remain, which involves welding tubes of the same material grade (10CrMo9-10) that do not require PWHT [6] for tube size 32x4.

But, if the entire reheater assembly is made of X10CrMoVNb9-1 steel, then field welding of the tube coils and the associated PWHT pose a real problem. In such a case, it is better to dismantle the inlet and outlet header, refurbish them in the workshop, and then install the entire assembly in several sections, as shown in Fig. 1. This represents a large volume of work, causing a long downtime. The goal when performing an overhaul of a power plant unit, such as a boiler or turbine, is to minimize the duration of the intervention and, consequently, the downtime.

Very often, in cases requiring rapid intervention on power plant boilers, Ni-based austenitic filler material [7] is used for welding to avoid the need for PWHT. These welding technologies appear attractive because they save time and money [8]. But for a weld to be considered successful, it needs to meet the acceptance criteria. For X10CrMoVNb9-1 steel, the most critical criteria to be met during welding concern the hardness in the heat-affected zone (HAZ) and the microstructure—specifically, the absence of untempered martensite [9,10].

Since the direct welding of thin-walled X10CrMoVNb9-1 steel tubes using an austenitic Ni-based filler material without PWHT is encountered in practice—yet no qualified welding procedure could be found—this paper examines such a case and presents the test results.

2. EXPERIMENT

The experiment was designed such that 9 test specimens were prepared by directly welding X10CrMoVNb9-1 steel, without PWHT (fig.5). Two types of filler material were used: Thermanit Nicro 82 TIG wire (2.4 mm diameter) and NIBAS 70/20-IG (2.0 mm diameter).

Specimens marked with No. 1–4 were welded using NIBAS filler material in three passes. Specimens marked with No. 5–8 were welded using T. Nicro 82 filler material in two passes. Speciment No.9 was welded with both filler materials, in two passes (root weld with Nibas, and cap weld with T. Nicro 82).



Fig.5: Nine pairs of tubes intended for welding samples made of X10CrMoVNb9-1 steel

For all specimens, welding was performed with argon purging. For the case where welding was performed using NIBAS filler material, the root pass was welded at I=80 A and U=13.2 V, while the subsequent passes were welded at I=85 A and U=13.4 V. For the T. Nicro 82 filler material, the root and cap passes were welded at I = 90 A and U = 13.5 V.

Tab.1: Mechanical properties of sample tubes used for speciments

Grade	Rp0.2 [MPa]	Rm [MPa]	A, [%]	HB	KV [J]	T [°C]
X10CrMoVNb9-1	450	630-830	19	/	/	20
Samples	585	690	22.3	-	-	20

Tab.2: Mechanical properties of filler rods

Grade	Rp0.2 [MPa]	Rm [MPa]	A, [%]	HB	KV [J]	T [°C]
Thermanit Nicro 82	400	620	35	/	150	20
NIBAS 70/20-IG	440	680	42	/	190	20
Filler rod 2.4 mm	-	1085	-	-	-	20
Filler rod 2 mm	-	1655	-	-	-	20

The fracture surface of the T. Nicro 82 filler rod has a specific appearance resembling a brittle fracture, with a coarse-grained structure (fig.6).



Fig.6: Break surface of sample No.9, welded with T. Nicro 82 (coarse break surface)

The 9 prepared specimens were tested according to the following plan:

- those that are labeled with No. 3, 4, 5, 6, and 9 were subjected to tensile testing at room temperature, metallographic analysis, and hardness testing,
- those that are labeled with 1 and 8 were examined in the undeformed state—using metallography and hardness testing—to avoid the effect of strain hardening,
- specimens 2 and 7 were subjected to short-term tensile testing at an elevated temperature of 630°C.

The results from the abovementioned tests were obtained in the following format:

- at which location does failure occur during the tensile test at room and elevated temperatures (in the base metal, the heat-affected zone, or the weld zone),
- Metallographic analysis determines whether untempered martensite is present in the welded joints within each zone,
- The Vickers hardness test provides the answer as to whether the welded joints comply with the technical requirements of the standard ISO 15614-1and the VGB-S-013 norm.

If one of the above-mentioned criteria is not met, the technology is considered unsuccessful.

3. RESULTS AND DISCUSSION

The structure of the base material consists of tempered martensite, carbides, and a small amount of retained austenite. The structure is homogeneous throughout the cross-section and is characterized by an exceptionally fine primary austenite grain, which resulted in a very fine and homogeneous microstructure after heat treatment (quenching and tempering).

The structure of the heat affected zone (HAZ) consists of untempered martensite and beinite. The weld metal structure is cast, dendritic, and austenitic, with a small amount of delta ferrite. There is no significant difference in microstructure between the samples (fig.7).

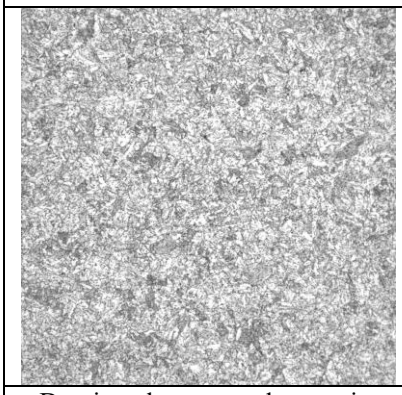
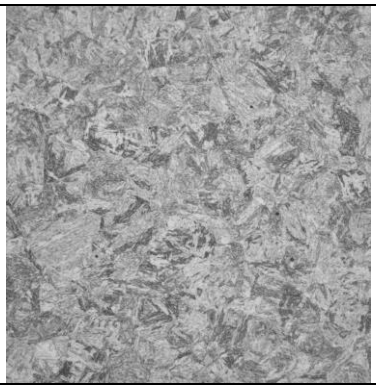
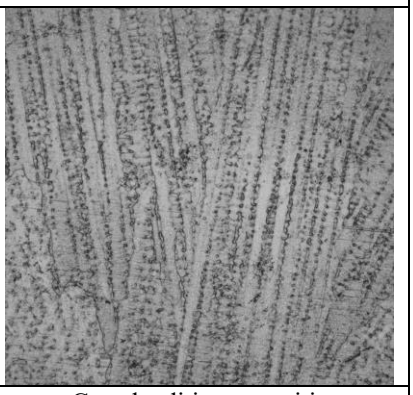
BM	HAZ	MW
		
Dominantly tempered martesite +carbides+retained austenite	Untempered martensite +bainite	Cast denditic+austenitic +delta ferrite

Fig.7: Representative microstructure in the weldment found in all 9 test samples

The acceptable hardness values for the welded joint of X10CrMoVNb9-1 steel are given in Tab.3. The presence of untempered martensite in the heat-affected zone (fig.7) contributes significantly to the high hardness measured (tab.5), which exceeds the permissible limits specified in tab.3.

Tab.3: Acceptable levels of Vickers hardness for X10CrMoVNb9-1 weldment

Standard/Norm	Weld metal HV	HAZ HV	Base metal HV
VGB-S-013	≤ 300	≤ 320	200 to 260
ISO 15614-1	≤ 350	≤ 350	≤ 350

Tab.4: Tensile test at elevated temperatures of 630°C

Sample No.	Rm,630°C [MPa]	Break location
2	458	BM
2	385	BM
7	416	BM
7	403	BM

Tab.5: Results from metallography and hardness test

1	Sample for hardness test	HV 5 values		
		Position	Cap	Root
		BM 1	211, 201, 2019	222, 221,220
		HAZ 1	409, 399, 330	426, 463, 416
	Only metallography and hardness (non-deformed)	MW	162, 155, 165	173, 150, 170
		HAZ 2	402, 412, 420	444, 421, 414
		BM 2	201, 213, 210	218, 222, 221

3	Sample for hardness test	HV 5 values		
	  Break location (BM)	Position	Cap	Root
		BM 1	212, 218, 210	230, 226, 214
		HAZ 1	418, 411, 415	450, 429, 424
		MW	194, 210, 210	259, 219, 258
		HAZ 2	413, 424, 429	461, 442, 422
		BM 2	227, 219, 221	225, 226, 231

4	Sample for hardness test	HV 5 values		
	  Break location (BM)	Position	Cap	Root
		BM 1	238, 233, 238	239, 242, 232
		HAZ 1	412, 428, 448	459, 460, 453
		MW	227, 217, 203	235, 249, 222
		HAZ 2	469, 462, 459	360, 356, 409
		BM 2	233, 227, 231	221, 237, 240

5	Sample for hardness test Break	HV 5 values		
	  Break location (MW)	Position	Cap	Root
		BM 1	224, 223, 224	231, 230, 231
		HAZ 1	413, 416, 407	429, 428, 433
		MW	277, 224, 303	310, 281, 286
		HAZ 2	421, 424, 429	422, 423, 420
		BM 2	225, 226, 230	234, 235, 233

6	Sample for hardness test	HV 5 values		
	  Break location (BM)	Position	Cap	Root
		BM 1	222, 221, 209	219, 221, 220
		HAZ 1	420, 411, 425	430, 428, 423
		MW	237, 236, 187	204, 209, 241
		HAZ 2	402, 417, 427	411, 428, 422
		BM 2	227, 227, 210	225, 227, 235

8	Sample for hardness test	HV 5 values		
		Position	Cap	Root
		BM 1	208, 205, 200	224, 219, 203
		HAZ 1	393, 364, 415	417, 429, 418
	Only metallography and hardness (non-deformed)	MW	140, 148, 156	146, 145, 165
		HAZ 2	374, 413, 421	402, 410, 419
		BM 2	199, 207, 211	209, 210, 212

9	Sample for hardness test	HV 5 values		
	  Break location (MW)	Position	Cap	Root
		BM 1	219, 228, 223	214, 221, 216
		HAZ 1	408, 421, 410	425, 418, 410
		MW	250, 287, 277	233, 254, 251
		HAZ 2	424, 410, 422	424, 428, 428
		BM 2	217, 224, 227	227, 231, 234

In the room-temperature tensile tests, only two specimens (specimens 5 and 9) exhibited a fracture point within the metal weld of the weld joint. The fracture surface appears coarse, a characteristic also observed in the T. Nicro 82 filler material itself.

In the elevated-temperature tensile test, both specimens marked as 2 and 7 fractured in the base material.

In general, it can be concluded that the welded joint made with NIBAS filler material was of higher quality than the one made with T. Nicro 82 filler material, when evaluated based on the tensile test.

A Charpy test was not performed because the pipes had a small wall thickness of 4 mm.

4. CONCLUSION

In both tensile test cases (sample No.5 and 9) where failure occurred in the welded joint, the cause of the failure was not a defect in the joint itself, but rather the undermatching of the weld relative to the base material. Generally speaking, no failure occurred during any of the tests in the heat-affected zone.

If the acceptance criteria are applied during the development of a qualified welding procedure for X10CrMoVNb9-1 steel without PWHT, such a procedure cannot be qualified. The EN 12952-5 standard clearly indicates in the note to Table 10.4-2 that, following welding, the X10CrMoVNb9-1 steel must first be fully transformed into martensite before undergoing PWHT. Otherwise, mixed phases such as bainite will form. Tempered martensite—and the effects of tempering in general—determines this steel's service life at elevated temperatures.

The small thickness and multi-pass welding did not have a microstructure-improving effect and cannot replace the effect of PWHT.

In practice, direct welding without PWHT can be considered only as a temporary repair solution, not as a replacement method.

Overall, the NIBAS filler material proved to be a better technical solution compared to T. Nicro 82.

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