Influence of the Diffusion Effect Caused by Welding Heat Input Lead to the Changes of Mechanical Properties Which Entering into the FEM Model of Cladding Tube Bending

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Abstract: This paper deal with redistribution of chemical elements around cladding surface of composite tube. Motivation is that change of chemical composition cause change in microstructure and mainly changes in mechanical properties. Local changes of mechanical properties can cause inaccuracy or wrong results obtained from FEM modeling of bending process of cladding tube. In short paper present redistribution of chemical elements caused by heat input during production of tube. Redistribution caused by heat input from weld attachment of connector which is used during production of membrane waterwall is discussed. Microstructure evaluation of base material and cladding layer is compared with measurement of hardness. Measurement of microhardness in specific areas of cladding tube was done. Microhardness is compared with measurement of chemical composition via EDX in scanning electron microscope.

Keywords: Cladding Tube, Welded Joint, SEM, Light Microscopy, Diffusion

1. Introduction

After reconstruction of high parametric coal power plants in the Czech Republic in the last 10 years there has been high-exfoliation of superheaters. The steam oxidation resistance increases with an increase in the concentration of chromium and the alloying Nb optionally Ti in austenitic steels. Furthermore, increasing the stability of austenitic phase of growth the concentration of nickel but also nitrogen. Alloying molybdenum has no direct influence on the formation of the protective chromium oxide or spinels.

Study steam side magnetite formation on austenitic steels at 600 - 700°C [1], [2], has led to the fact that the original steel 347H and 304 H were developed in the 80s steel HFG (Fine grained) and HSB or HSP (shot blasted or shot peening). Pipes of these fine-grained or blasted austenitic steels exhibit comparable resistance to steam oxidation behavior of high-alloyed austenitic steels HR3C and NF709.

Cheaper production component boilers brought cladding tubes. Technology of production of clad tubes was mastered by many other manufacturers (Figure 1, [6]) and a gradual decline in prices of clad tubes makes them an alternative to the

use of homogeneous tubes of high-quality metal, or to use overlay. Using clad tubes is subject by mastering the technological operations necessary for producing the normal technical equipment. One of technologically operation is bending of tubes. There is possibility to modeling of bend via FEM modeling. Another technological operations is welding of tubes into the shape of water walls. Welding can caused redistribution of chemical composition and through that change mechanical properties of clad tube. The paper describes some steps of investigation of influence of welding to the cladding tubes.

2. Test Experimental Materials

Diameters of the cladding tube and layers thickness are shown in Table 1[3]. Chemical compositions of used materials are demonstrated in Table 2 and Table 3 [4,5].

Table 1. Tube specification.

Sandvik 3R12/4L7 OD 76,2 x 6,58	
Outer diameter	72,9 mm
Total wall thickness	6,58 mm
Sandvik 3R12 thickness	1,65 mm

Table 2. Sandvik 3R12.

C	Si	Mn	P	S	Cr	Ni
≤0.03	0.5	1.3	≤0.03	≤0.01	18.5	10

Table 3. Sandvik 4L7.

C	Si	Mn	P	S
≤0.20	0.3	0.7	≤0.025	≤0.020

Production route of composite tubes *Figure 1. Production of cladding tubes.***3. Results of Material Testing****3.1. Influence of Bending**

Experimental bend was realized on bending machine with inductor heating of tube. Inductor heat small ring of material which is preferably used for location of deformation. Process

of bending are shown in Figure 2.

First step was modeling of bend made from clad tube. The aim of modeling was calculation of deformations across the tube (Figure 3, [8]) and shear stresses at the cladding surface. FEM model was firstly used for modeling bend made from cladding tube Sanicro38/4L7. Results of shear stresses from modeling of tube segments for tension, pressed and neutral part of tube are plotted in Figure 4.

Figure 2. Upper view during bending. *Figure 3. Scheme of deformations across the tube.* *Figure 4. Shear stresses in the XY plane.*

Results from FEM modeling was compared with measurement of critical shear stresses which caused delamination of cladding layers. Comparison of calculated shear stresses and critical shear stress confirm correct bending parameters and gave possibility to make real bend of tubes without problems with delamination of layers [7, 8].

Microscopy confirmed homogenous of clad surface without delamination. Microstructure near cladding surface is shown in Figure 5. There is a carbon depleted zone with thickness up to 85 μm . Diffusion of carbon is caused by heat input during producing of tube and by different in carbon content in Sanicro 38 and 4L7 [9]. Diffusion into Sanicro 38 is retarded by high content of nickel. Difference in content of carbon across cladding surface is marked with red color in Figure 6.

Table 4. Chemical composition of Sanicro 38.

Sanicro 38	
C	$\leq 0,03$
Si	$\leq 0,5$
Mn	0,8
Cr	20
Ni	38,5
Mo	2,6
Cu	1,7
Ti	0,8

Figure 5. Structure around the cladding surface.

Figure 6. Line analyses across cladding surface.

Measurement of chemical composition and microhardness (Figure 7) suggests differences in mechanical properties around cladding surface. Those differences can cause deviation between FEM model and real bend.

Figure 7. The measurement of microhardness.

3.2. Influence of Welding

Above mentioned redistribution of chemical composition caused by heat input during producing of tubes isn't significant in case of combination Sanicro38/4L7. Sanicro contain 38% of nickel which acts as a diffusion barrier. Combination of 3R12 and 4L7 can exhibit different. Steel 3R12 contain 10 % of nickel. Another difference can be caused by welding joints of tubes together into tube walls. Scheme of cutting of tube is shown in Figure 8. Macro photos of cuts from the tube are in Figure 9.

Figure 8. Scheme of cut of the tube.

Figure 9. Cuts from the tube.

3.2.1. Microstructures

Recrystallized microstructure of steel 4L7 with fine lamellar perlite and grain size 9 [10] is shown in Figure 10. In Figure 11 austenitic structure of steel 3R12 with grain size 7 [10], twins and disperse carbides is presented.

Figure 10. Microstructure of steel 4L7 (320x).

Figure 11. Microstructure of steel 3R12 (320x).

Carbon depleted zone in steel 4L7 with thickness about 110 µm and rougher grain in comparison with base material (Grain size 7 [10]) is presented in Figure 12.

Figure 12. Microstructure of cladding surface side of steel 4L7 (320x).

Austenitic structure near cladding surface containing carbide precipitation and 5 µm thickness zone with high concentration of slipping lines is shown in Figure 13.

Figure 13. Microstructure of cladding surface side of steel 3R12 (320x).

3.2.2. Hardness Measurement

Position of hardness measurement one can see in Figure 14. Comparison of hardness measurement results is listed in Table 5. There is possible to see difference among base tube and tube under connection weld. Value of measured hardness was higher under weld for both materials. Difference is about 20 HV10.

Figure 14. Position of hardness measurement.

Table 5. Measurement of hardness.

Measured crossection	Structure	Average hardness
Crossection A	austenite	172 ± 2 HV10
	ferrite	151 ± 4 HV10
Crossection B	austenite	192 ± 5 HV10
	ferrite	167 ± 4 HV10

3.2.3. Microhardness Measurement

Microhardness across cladding surface is shown in Figure 15. Value 0 at X axis represent cladding surface. Positive positions represent measured value in austenite (3R12) and negative in ferrite (4L7).

Carbon depleted zone in steel 4L7 exhibit lower hardness, but carbon enrich zone in austenitic steel 3R12 exhibit markedly higher microhardness in comparison with base austenite material.

Figure 15. Microhardness around cladding surface.

In order to better describe of hardness pursuant on chemical composition several areas was selected and named oblast I – oblast VII (Figure 16). In these areas was measured microhardness and chemical composition. In each area was done five measurement of microhardness with increments 0,2 mm. Results of microhardness measurement are listed in Table 6.

Figure 16. Zones for measurement of Microhardness around cladding surface.

Table 6. Results of Microhardness measurement around cladding surface.

Crosssection	Area	Average hardness
Crossection A	I	179 ± 3 HV0,1
	II	146 ± 9 HV0,1
	III	142 ± 7 HV0,1
	IV	216 ± 22 HV0,1
	V	369 ± 41 HV0,1
	VI	269 ± 16 HV0,1
	VII	229 ± 12 HV0,1
Crossection B	I	171 ± 13 HV0,1
	II	154 ± 4 HV0,1
	III	154 ± 3 HV0,1
	IV	223 ± 13 HV0,1
	V	405 ± 36 HV0,1
	VI	232 ± 6 HV0,1
	VII	227 ± 7 HV0,1

3.2.4. Chemical Composition Measurement

Measurement of chemical composition was done by EDX at the scanning electron microscope JEOL.

Positions of measured areas for crosssection A are shown in Figure 17. Equivalent full spectra are plotted in Figure 19.

Table 7 summarized results of measurement of chemical composition of crosssection A.

Positions of measured areas for crosssection B are shown in Figure 18. Equivalent full spectra are plotted in Figure 20.

Table 8 summarized results of measurement of chemical composition of crosssection B.

Figure 17. Position of chemical composition measurement areas for crosssection A.

Figure 18. Position of chemical composition measurement areas for crosssection B.

Figure 19. Comparison of full spectra for crosssection A.

Figure 20. Comparison of full spectra for cross-section B.

Table 7. Summarize table of chemical composition for cross-section A.

Spectrum	C	Si	Cr	Mn	Fe	Ni
Spectrum 1	3.22	0.41		0.76	95.56	
Spectrum 2	3.12	0.44		0.79	95.60	
Spectrum 3	2.70	0.42		0.81	96.03	
Spectrum 4	3.19	0.42	1.13	0.78	93.87	0.55
Spectrum 5	3.78	0.40	4.80	0.91	87.55	2.48
Spectrum 6	4.35	0.46	13.66	1.44	71.94	7.19
Spectrum 7	2.48	0.50	18.64	1.42	66.86	9.91

Table 8. Summarize table of chemical composition for cross-section B.

Spectrum	C	Si	Cr	Mn	Fe	Ni
Spectrum 1	4.24	0.44		0.75	94.54	
Spectrum 2	3.65	0.41		0.77	95.10	
Spectrum 3	3.47	0.44		0.75	95.29	
Spectrum 4	5.34	0.44	12.47	1.17	75.11	5.30
Spectrum 5	3.98	0.47	19.52	1.36	64.97	9.47
Spectrum 6	3.05	0.50	18.73	1.42	66.40	9.70
Spectrum 7	3.01	0.51	18.44	1.44	66.58	9.84

4. Conclusions

- It was confirmed that it is possible to model bending process of cladding tube
- In case of tube with high nickel content cladding layer is diffusion of chemical elements negligible
- Cladding tube with layer containing lower content of alloying elements (especially nickel which act like diffusion barrier) exhibit more changes in microstructure and in mechanical properties
- There is higher thickness of carbon depleted zone in steel type 4L7. In this zone is documented drop of microhardness
- Influence of welding is unfavorable. Weld mean higher heat input which accelerated diffusion of chemical components
- These changes of chemical composition lead to decrease of hardness in dough layer of cladding tube
- Weld caused higher differences in microhardness around the cladding surface. There is difference in microhardness around 250 HV0,1. Increase in

microhardness is caused by carbon diffusion followed by precipitation of carbides around cladding surface

- Difference in microhardness suggests high differences in all mechanical properties of tube layers
- It will be necessary to include this differences into FEM bending model of cladding tubes

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