10th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2006, Barcelona-Lloret de Mar, Spain, 11-15 September, 2006

DAMAGE DETERMINATION OF THE BOILER PLANT COMPONENTS MATERIAL DUE TO LOW CYCLING FATIGUE BASED ON THE TRD REGULATIONS

Halima Hadžiahmetović, BSc, Energoinvest Sarajevo
e-mail: halima_hadziahmetovic@yahoo.com

ABSTRACT
During exploitation, material of the steam preheater is changed by degradation of its properties. Permanent controls and periodical testing are necessary in order to establish present state of the material. The goal of the testing was to determine influence of the work regime on the material behaviour according to exploitation time.
Low cyclic fatigue is basic process which influence on the exploitation time of some preheater components. In this paper is suggested model for the evaluation level of the exhaustion high loaded components because of low cyclic fatigue in parts of the boiler plant UKO-3 ,,Natron'' Maglaj. Translation of TRD regulations is used for evaluation of the exhaustion. TRD regulations are used as a base of the investigation. Mechanical testing was done in mechanical laboratory of Metallurgy Institute "Kemal Kapetanović" in Zenica.
Key words: low cyclic fatigue, degradation of materials, TRD regulation

1. TESTING OF STEAM PREHEATERS PIPE SYSTEM OF BOILER PLANT UKO-3

Steam preheaters is designed in four levels. Figure one shows a cross section of the preheater with layout of measured points. Pipe material is steel 13CrMo44 (DIN 17 175) and dimensions are Ø 34×3,2 mm. Tension strength testing are done on sample taken from II, III, and IV levels of preheater (testing temperature 25°C). Mechanical testing was done in mechanical laboratory of Metallurgy Institute "Kemal Kapetanović" in Zenica, and results are presented in table 1. According to DIN 17 175 (for steel 13CrMo44, room temperature) tensile strength should be within range of 440-590 N/mm^2. From the result in table one we can see that only one sample has necessary value of the tensile strength.

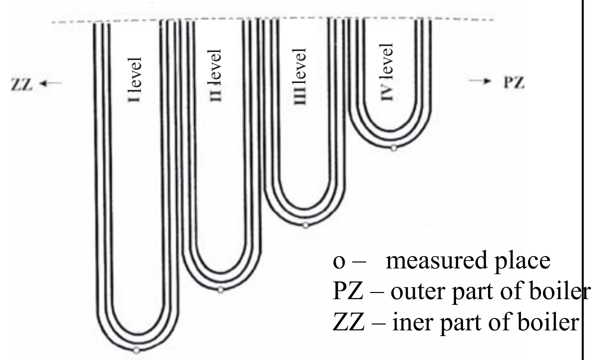

Figure 1. Cros section of boiler of preheater with layout of measured place [1]

Table 1. Results of mechanical testing.

Number of class	Mark of tube	Temp. of testing (°C)	$Rp_{0.2}$/Re (N/mm^2)	R_m (N/mm^2)	Max. force Fm (N)	A (%)	Z (%)
1.	Right side –II level	+25	328	477	34650	32	67
2.	Right side –III level	+25	263	428	31870	37	70
3.	Corner α =180°C-III level	+25	313	433	31960	31	65
4.	Left side –IV level	+25	265	378	26970	51	70

2. TRD REGULATIONS

Degree of damage of the preheater material, which is most important for making decision of replacement some parts of the preheaters, can be determine using German TRD regulation rules (TRD 500, TRD 300).According TRD regulations determination of damage degree of the material can be done by modelling real condition and its influence on exploitation time of the material.

Technical characteristic of boiler machinery UKO-3 ("Natron" Maglaj).

Capacity: 80/64 t/h

Max. steam pressure: 80 bars

Temperature of preheated steam: 450^0C

Temperature of tension water: 105^0C

Minimal thickness of steam preheaters pipe walls: s_v=3,5 mm

Number of estimated class: 6

The necessary date for determination of damage degree of materials are: overpressure, temperature, temperature gradients in wall of components in period of exploitation for which evaluation is being made. The very important are also mechanical and thermical stresses inducted during period of starting and ending the boiler plant. According to TRD regulations is necessary to determine reduced range of tension ($\Delta\sigma_i$), and real range of tension using data for average temperature (ϑ^*) of each cycles. Using basic formula $\vartheta^* = 0{,}75 \cdot \hat{\vartheta} + 0{,}25 \cdot \breve{\vartheta}$ we get:

$$\vartheta^* = 0{,}75 \cdot 460 + 0{,}25 \cdot 0 = 345\ °C$$

Where:

$\hat{\vartheta}$ = 460°C is maximal registered temperature

$\breve{\vartheta}$ = 0°C is minimal registered temperature in due of watching machinery cycle.

If the wall thickness is unknown than it can be calculated as follows::

a) If s_e is some average thickness of wall, than the value of estimated thickness of wall is $s_b = s_e$.
b) If s_e is some minimal thickness of wall, than $s_b = 1{,}15\ s_e$ (for the pipe), and $s_b = s_e+1$ (for outer layer).

In this calculations the inner diameter is known (d_i = 26,8 mm) so it can be calculated the outside diameter (d_a) and average diameter (d_m), as it follows:

$$d_a = d_i + 2\ s_b = 26{,}8 + 2 \cdot 3{,}5 = 33{,}8\ mm$$
$$d_m = 0{,}5 \cdot (d_a + d_i) = 0{,}5 \cdot (33{,}8 + 26{,}8) = 30{,}3\ mm.$$

For each temperature class corresponding reduced range of tension $\Delta\sigma$ (according to upper temperature and TRD regulations) is calculated as follows

$$\Delta\sigma_i = \left(\alpha_m \cdot \frac{d_m}{2 \cdot S_b}\right) \cdot \Delta p + \left(\alpha_\vartheta \cdot \frac{\beta_{L\vartheta} \cdot E_{L\vartheta}}{1-\nu}\right) \cdot \Delta\Theta,$$

Where: α_m - coefficient for membranes tension

α_m- Coefficient for termic tension of temperature ϑ^*

$\beta_{L\vartheta}$ - linear coefficient of differential termic spreading for temperature ϑ^*, (table 2),

$E_{L\vartheta}$ - Module of elasticity for temperature ϑ^*, is given in table 3,

ν - Poison's coefficient

Table 2. Results of experimental deciding of lineardifferential coefficient of warm spreading (10^0/°C) [1]

Temperature (°C)	13 CrMo 44 15 Mo 3 14 MoV 63
316	15,4
371	15,9

Table 3. Dependence of module elasticity of ferital steel of temperature [1]

Temperature	[°C]	300	400
Module of elasticity	*[GPa]*	190	182

According to: $2 \cdot \sigma_a = \Delta\sigma_i \cdot f_3 \cdot \frac{\Delta\sigma_i}{2 \cdot \sigma_{0,2/\vartheta^*}}$ za $\Delta\sigma_i > 2 \cdot \sigma_{0,2/\vartheta^*}$ and $2 \cdot \sigma_a = \Delta\sigma_i \cdot f_3 \cdot \frac{(2 \cdot \sigma_B)^2}{(2 \cdot \sigma_B)^2 - (2 \cdot \sigma_{0,2/\vartheta^*} - \Delta\sigma_i)^2}$, za $\Delta\sigma_i \le 2 \cdot \sigma_{0,2/\vartheta^*}$ given in TRD Regulation 301, to every value of reduced range of tension $\Delta\sigma_i$ corresponding to the real range of tension $2\sigma_a$. The value of coefficient $f_3 = 1$, steel with ferits structure. Dependence of $Rp_{0,2}$ for ferits boiler steel on temperature is given in table 4.

Table 4. $Rp_{0,2}$ for steel 13 CrMo 4 4 [3]

Number of classes	wall thickness [mm]	$Rp_{0,2}$ [N/mm²]						
		200 [°C]	250 [°C]	300 [°C]	350 [°C]	400 [°C]	450 [°C]	500 [°C]
1.	≤ 40	240	230	215	200	190	180	175
2.	40< s ≤ 60	230	220	205	190	180	170	165
3.	60< s ≤ 80	220	210	195	180	170	160	155

In table 1 minimal tensile strength on room temperature for steel 13 CrMo 44 is $\sigma_B = 378\ N/mm^2$.
Value of parameters S_1, S_2 and S_3 are:

$$S_1 = 78724{,}99997 + \frac{965775936{,}9}{\vartheta^* - 13137{,}5} = 78724{,}99997 + \frac{965775936{,}9}{345 - 13137{,}5} = 3229{,}51927$$

$$S_2 = 2877{,}06645 + \frac{4861735{,}668}{\vartheta^* - 2542{,}868719} = 2877{,}06645 + \frac{4861735{,}668}{345 - 2542{,}868719} = 665{,}04322$$

$$S_3 = 528{,}0508475 + \frac{261452{,}4563}{\vartheta^* - 1448{,}305085} = 528{,}0508475 + \frac{261452{,}4563}{345 - 1448{,}305085} = 291{,}0788079$$

From the S_1, S_2 and S_3 parameters A, B, C can be calculated as follows:

$$A = \frac{S_1 \cdot S_3 - S_2^2}{S_1 - 2 \cdot S_2 + S_3} = \frac{3229{,}51927 \cdot 291{,}0788079 - 665{,}04322^2}{3229{,}51927 - 2 \cdot 665{,}04322 + 291{,}0788079} \Rightarrow A = 227{,}235556$$

$$B = \frac{S_1 - S_2}{C^2 \cdot (1 - C^2)} = \frac{3229{,}51927 - 665{,}04322}{0{,}38187024^2 \cdot (1 - 0{,}38187024^2)} \Rightarrow B = 20588{,}2816$$

$$C = \sqrt{\frac{S_2 - S_3}{S_1 - S_2}} = \sqrt{\frac{665{,}043223 - 291{,}0788079}{3229{,}51927 - 665{,}043223}} \Rightarrow C = 0{,}381870$$

Number of cycles to breaking n_k is calculate to formula: $\hat{n}_k = 10^{\frac{\log(2\sigma_a - A) - \log B}{\log C}}$. Using formula $e_{w,k} = \frac{n_k}{\hat{n}_k} \cdot 100$ can be calculated damage of each part for each of these temperature classes.

Table 5. Table sample of counted values of reduced spread of tension and the real spread of tension

The class of estimate	ΔΘ [°C]	$\Delta\sigma_i$ (reduced range of tension) [N/mm²]	$2\sigma_a$ (the real range of tension) [N/mm²]
1.	20	175,87200	192,81924
2.	40	342,74057	344,71806
3.	55	467,89200	547,30731
4.	70	593,04343	879,25127
5.	85	718,19486	1289,50963
6.	100	843,34629	1778,08239

Table 6 . Calculated values of cycle number to breakage and partial exahust

The class of estimate	**$2\sigma_a$ [N/mm^2]**	**$\hat{n}_k$ (the number of cycles to breaking)**	**$e_{w,k}$ [%]**
1.	192,81924	∞	0
2.	344,71806	232538,84084	0,13331
3.	547,30731	21153,36555	1,37094
4.	879,25127	3857,16528	1,37407
5.	1289,50963	1200,17539	2,91624
6.	1778,08239	485,49453	2,05976

Total damage after lowcyclic fatigue is equal to sum of partial exhaust $e_{w,k}=\sum_k e_{w,k}$ to every temperature classes:

$$e_w = 7,85431\ \%$$

3. CONCLUSION

In this work, on basis of GERMAN TRD REGULATIONS, is suggested the model for determination of material damage of highpressured components of steam boiler plant made of ferit steel during the exploitation after lowcyclic fatigue. In the basis of model are temperature classes in working condition of boiler plant. Division on temperature classes in case of lowcyclic fatigue is made on the data of temperature gradient in walls of component. In results of mechanic testing are given the values of tension strength on samples taken from preheaters steam. Three samples had shown lower strengthness and only one had higher strengthness than 440 N/mm^2. After all calculations The damage degree of the material was 7,78% due to low cycle fatigue. To give final conclusions about material some other investigation should be carried out, for example: metallographic investigation and creep testing.

4. REFERENCES

[1] Halima Hadžiahmetović: Diploma work, "Estimate of exhaust material of highpressured components of boiler plant", Zenica, June 2004. year.

[2] DIN 17 175

[3] TRD REGULATIONS