Fatigue calculation of “SH” drainpipes

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Abstract: *During the combustion processes of fuels, fuel gasses are created which flow over the heat exchanger. The flow of fuel gasses brings ash particles which are deposited on heat exchanger surfaces and thus reduce the heat exchange efficiency. The removal of ash deposits from the heat exchanger is performed by a striker. Striker indirectly strikes the floor of the lower chamber of the heat exchanger via the mandrel and transmits kinetic energy to it. The impact results in inertial forces on the layer of deposits that are greater than those of adhesion forces between the surface of the exchanger pipes and the ash deposits. The pipes are loaded with displacement caused by the impact of a mandrel used to clean the heat exchanger, displacement caused by the operating pressure inside the pipe, and thermal elongation. The load of the pipes is cyclic, and calculation was performed according to the standards: EN 12952-3:2012-03 and EN 13445-3:2009. The calculation was performed at critical pipe cross-sections. The Abaqus/CAE2016 software package was used to determine the critical cross-sections of pipes and stress that occur in them. The model was created using beam finite elements. After analyzing the stress and applying the standards, a conclusion is reached on the fatigue strength of the drainage pipes. The heat exchanger pipes are made of austenitic W.Nr.2.5956 and 16Mo3 steels. The pipe with maximum fatigue stress of 208 MPa is made of 16Mo3 steel, which has a tensile strength from 450 to 600 MPa. Young modulus of elasticity at an operating temperature of 383 ° C is E = 173,9 GPa. The permanent strength diagram is taken from EN 12952-3: 2011 standard shows that this material can withstand 10^7 cycles with such fatigue stress, and the required number of cycles is determined based on the customer's request which is the projected number of years. The plant is projected on operating 5 years. The designed number of cycles is 350400 cycles, so it is concluded that the pipes satisfy the conditions of exploitation.*
Keywords: *FATIGUE, IMPACT LOAD, STEAM BOILERS, HEAT EXCHANGER, DRAINAGE PIPES*

1. Introduction

Experience shows that fracture of structures or machine parts during regular operating conditions are most often due to fatigue.

Fatigue or fatigue damage refers to the modification of the properties of materials due to the application of stress cycles whose repetition can lead to fracture.

Uniaxial loading is defined as *the amplitude of the maximum stress* during a cycle s_{max}. The *stress ratio* R is the ratio between the *minimum stress* s_{min} and the *maximum stress* s_{max}, $R = s_{min}/s_{max}$.

We sometimes must distinguish the *alternating component* s_a from the mean stress s_m. Thus, depending on the relative values of these two components, we can differentiate the tests under different stresses (see Figure 1.6), such as:

- fully reversed: $\sigma_m = 0$, $R = -1$;
- asymmetrically reversed: $0 < \sigma_m < \sigma_a$, $-1 < R < 0$;
- repeated: $R = 0$;
- alternating tension: $\sigma_m > \sigma_a$, $0 < R < 1$. [1]

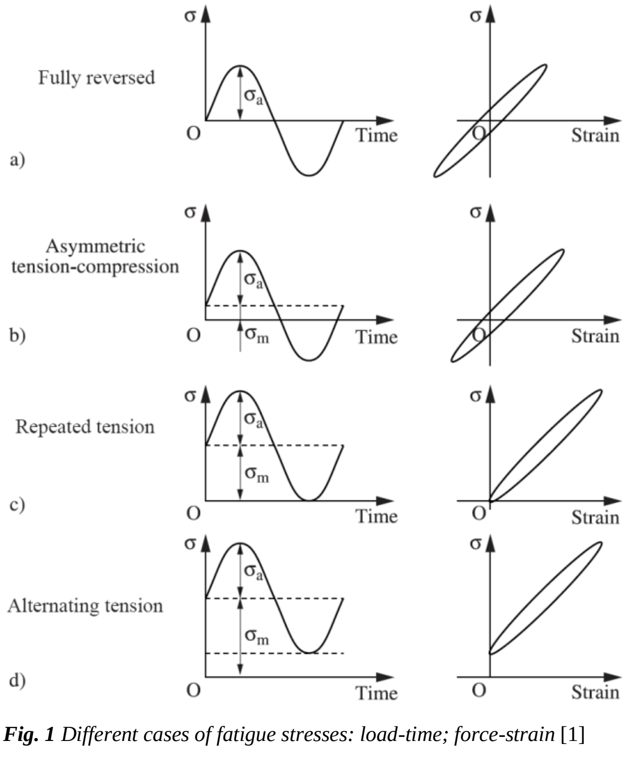

Fig. 1 *Different cases of fatigue stresses: load-time; force-strain* [1]

Electrical energy has a rising form of use in everyday activity, therefore, producing electrical energy is important in present-day life.

Incineration is used as a treatment for a very wide range of wastes. Incineration itself is commonly only one part of a complex waste treatment system that altogether provides for the overall management of the broad range of wastes that arise in society. The objective of waste incineration is to treat wastes to reduce their volume and hazard, whilst capturing (and thus concentrating) or destroying potentially harmful substances that are, or may be, released during incineration. Incineration processes can also provide a means to enable recovery of the energy. [2]

Waste incineration installations are producers of electricity which transform burning energy from different waste to electrical energy. Burning fire from waste and its smoke that runs through smokestack is heating up the water in pipes that are part of waste incineration installations.

Ashes from the smoke can accumulate on pipes that are filled with water (heat exchangers), therefore, ashes must be cleaned so that heating of water can continue. Cleaning of ashes is done by thorn impact that drains the ashes from the heat exchanger. On those heat exchangers are located drainpipes that enable water drain in time of no use of waste incineration installations.

Thorn impact on heat exchangers and drainpipes is presenting a cyclic load of drainpipes used in this paper.

Drainpipes are moved by thorn impact up to ±11 mm and those are two types of load, Step A (-11 mm) and Step B (+11 mm). Also, there is pipe displacement due to thermal expansion which occurs because of the different temperatures of water inside of heat exchangers.

Fatigue calculation in this paper is calculated for drainpipes SH3.2, SH3.1, and SH1.2. SH 3.2 drainpipes have the highest calculation temperature which is the most critical case. However, because the different material is used to produce drainpipes, calculations are repeated for SH3.1 and SH 1.2 drainpipes.

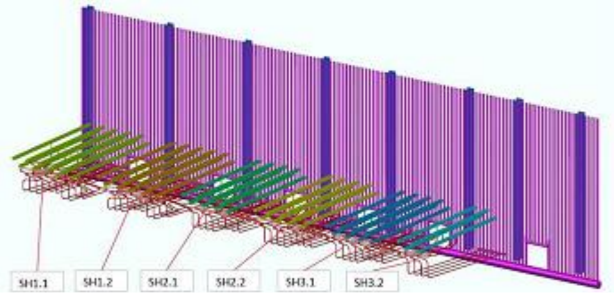

Fig. 2 *Drainpipes*

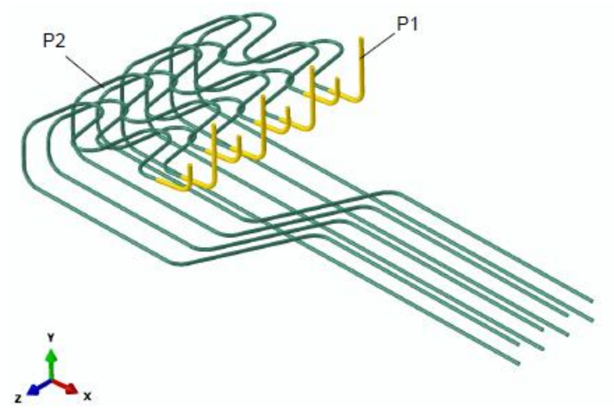

Fig. 3 *SH 3.2 drainpipes model*

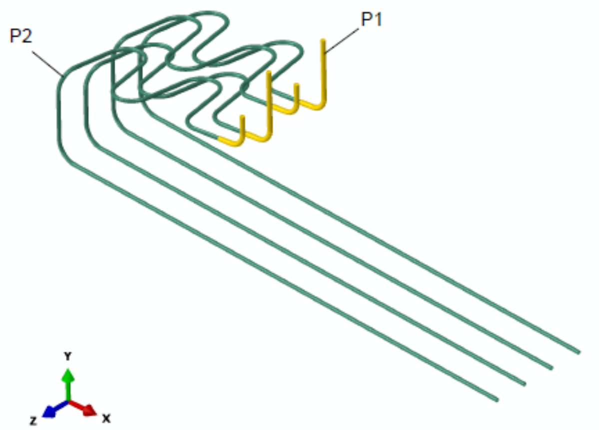

Fig. 4 *SH 3.1 drainpipes model*

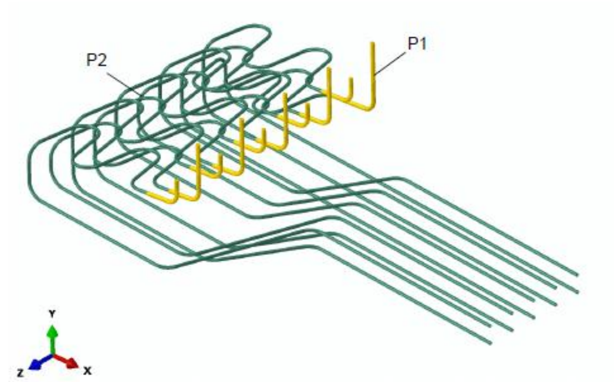

Fig. 5 *SH 1.2 drainpipes model*

2. Prerequisites and means for solving the problem

Numerical calculation is used for obtaining different sorts of results like axial force, bending moments, and twisting moment. After placing different displacements on each group of drainpipes due to thorn impact and thermal elongation, the next steps are to put gravity load on pipes and fix lower parts of pipes. Materials properties are included for pipes, and mesh is made by standard beam elements (B31), 5 mm of size. The calculation is performed in Abaqus/CAE 2016 and after obtaining these results, analytical calculation follows.

Analytical calculation is made by combining two similar standards, EN 12952-3:2012-03 and EN 13445-3:2009. Each drainpipe has 4 critical cross-section which occurs firstly on the place of connections of drainpipes and heat exchangers (P1 pipe), secondly on the connection of different pipes (P1 and P2). The next critical cross-section is on the rounded part of the drainpipe with maximal stress, last critical cross-section is on the lower part of pipes, a connection between pipe and shell. The calculation is performed for every pipe in each group of drainpipes and due to similarities in geometry, some pipes are calculated together.

After creating a numerical model of pipes and solving them, the next step is to read results in critical cross-section. In this part, it is important to read different results on each pipe in the same elements. Also, it is important to read the highest absolute values of different results in each element.

3. Preliminary calculations

After reading the values of forces and moments from the Abaqus 2016 software package, these values are included in the formulas for calculating stresses in previously agreed cross-sections. The stress caused by the bending moment is calculated according to the expression $S_b = \frac{M_b}{W_x}$ where M_b represents the bending moment, and W_x is the axial moment of inertia. The shear stress is calculated according to the expression: $\tau = \frac{M_t}{W_p} = \frac{M_t}{2W_x}$ where M_t represents the torque, W_x is the axial moment of inertia. The axial stress is calculated according to the expression: $S_n = \frac{SF}{A_x}$ where SF represents the axial force, and A_x is the area cross-section. To determine the stress, it is necessary to know the geometric characteristics of the pipe cross-sections.

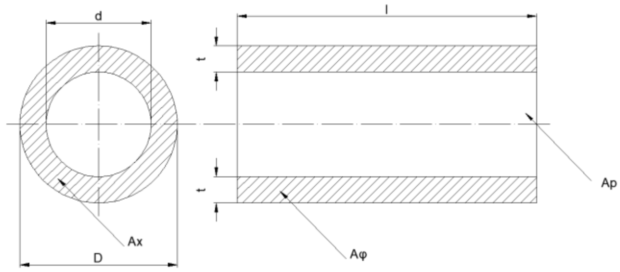

Fig. 6 *Dimensions and geometrical characteristics of the pipe cross-section*

Internal pressure in each pipe causes circular and longitudinal stress of the pipe. Pipes longitudinal stresses caused by internal pressure is calculated according to the expression $S_x = \frac{pd^2\pi}{4A_x}$, and circular pressure is calculated according to the expression $S_\varphi = \frac{pd}{2t}$. In those expressions p represents internal pressure, and other dimensions can be seen in fig. 6.

The next step is to determine the total stress in the x-axis direction. The total stress in the direction of x-axis is determined by the expression $S = S_x + S_b + S_n$. The principal stresses can now be calculated for the individual pipe cross-sections according to the expression $\sigma_{1,2} = \frac{S + S_{\varphi}}{2} \pm \sqrt{\left(\frac{S - S_{\varphi}}{2}\right)^2 + \tau^2}$.

After calculating all the necessary stresses for the application of standard, we can proceed to the calculation according to standards *EN 12952-3:2012-03 and EN 13445-3:2009.* To consider the welded joints, correction factors C_{k1}, C_{k2}, and C_{k3} are used, and for the quality of the treated surface is used C_{k0}. This case uses a weld on only one side so factor C_{k3} will be used. The values of the correction factors are shown in Table 1.

Table 1: *Correction factors Ck for taking account of the notch-effect associated with the influence of the weldments* [5]

Welded joints			
Tensile strength *R*m [N/mm2]	Configuration group K1 (slight notch effect)	Configuration group K2 (moderate notch effect)	Configuration group K3 (pronounced notch effect)
	C_{k1}	C_{k2}	C_{k3}
400	1,5 ≤ 0,19 lg N_a + 0,62 ≤ 1,8	1,6 ≤ 0,21 lg N_a + 0,79 ≤ 2,1	1,8 ≤ 0,34 lg N_a + 0,66 ≤ 2,8
600	1,7 ≤ 0,40 lg N_a + 0,20 ≤ 2,7	1,9 ≤ 0,40 lg N_a + 0,60 ≤ 3,1	2,1 ≤ 0,56 lg N_a + 0,40 ≤ 4,0
800	1,8 ≤ 0,56 lg N_a 0,12 ≤ 3,4	2,1 ≤ 0,56 lg N_a + 0,44 ≤ 4,0	
1000	1,9 ≤ 0,70 lg N_a 0,40 ≤ 4,0	2,5 ≤ 0,75 lg N_a + 0,25 ≤ 5,0	

Controlling stress range shall be determined depending on elastic range, partly elastic range, or fully plastic range. In case of a load, cycle temperature is higher than 100 ºC, the reduction in the fatigue strength caused by the temperature shall be taken into account by means of a correction factor C_{t^*}. The last step is to calculate the controlling stress range that takes the high temperature in fatigue calculation. [2,3]

4. Results of fatigue calculations

In chapter 3 is shown how to calculate the fatigue life of drainpipes, for each pipe in a different group of pipes calculation must be derived.

All calculated results, with those of fatigue life of drainpipes, are shown in Table 2.

Table 2: *Final results of stress calculation*

SH 3.2	$2 f_{at^*}^{*}$ [MPa]			
Pipe number	Cross-section 1	Cross-section 2	Cross-section 3	Cross-section 4
1-3	108	167	103	11
2-4	157	159	106	8
SH 3.1	$2 f_{at^*}^{*}$ [MPa]			
Pipe number	Cross-section 1	Cross-section 2	Cross-section 3	Cross-section 4
1-3	110	80	71	14
2-4	123	59	68	9
5-7	116	175	120	15
6-8	179	163	123	10
SH 1.2	$2 f_{at^*}^{*}$ [MPa]			
Pipe number	Cross-section 1	Cross-section 2	Cross-section 3	Cross-section 4
1	92	68	53	11
2	103	51	53	8
3	95	104	60	13
4	105	87	55	10
5-7	118	101	66	14
6	202	78	67	9
8	170	157	111	10
9	120	175	106	14
10	208	154	119	8

From table 1 can be seen that the maximum stress appears in pipe 10, SH 1.2. Comparing this value of stress to the diagram shown in the Figure 5, the pipe can withstand 10^7 cycles.

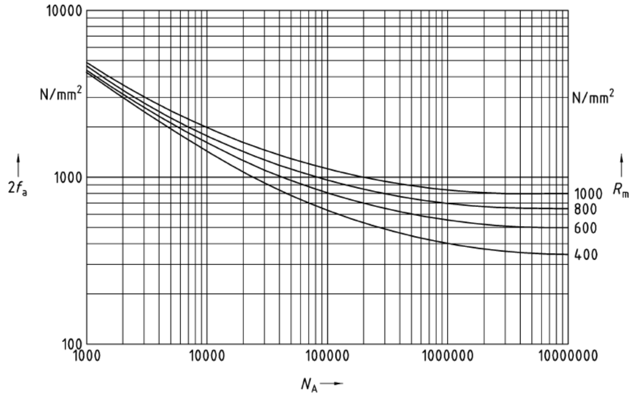

Fig. 5 *Number of load cycles N_A for crack initiation (mean value of the scatter band) as a function of the stress range for unnotched bar specimens of high-temperature ferritic rolled or forged steels at room temperature and $f_v = 0$* [5]

5. Conclusion

This paper describes the generation of electricity through waste incineration as a fuel source. The problem of fatigue that occurs in cyclically loaded structures is explained. Fatigue calculation was performed for each of the drainage pipes groups for four critical cross-sections.

The calculation was performed according to the norm for each of four agreed critical cross-sections from each group. It has been found that all pipes can withstand 10^7 cycles. It would be good to examine the credibility of the selected cross-section in such a way that every final element on one tube is subjected to the calculation.

Because of the great effort of performing such calculation, it will be of a big time-saver to use software like Fe-Safe to calculate fatigues life.

6. References

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