THERMAL FATIGUE CRACKING OF ESTONIAN OIL-SHALE-FIRED BOILERS' TUBES CAUSED BY ON-LOAD WATER DESLAGGING

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ANNOTATION

The results of the research in the field of thermal fatigue cracking on the outer surface of the 12Cr1MoV steel tubes working under the temperature of 400 °C in the furnace screen of boilers burning Estonian oil shale are presented.

Long-time, non-stop work of the oil-shale-fired boilers is ensured by the regular usage of the highly intensive water deslagging. In the cleaning cycles there arise thermal stresses in the tubes' wall of the heating surfaces thus causing the initiation and development of thermal fatigue cracking on their outside surfaces.

On the basis of field testing under actual boiler conditions during 40000 hours in the oil-shale-fired boiler general regularieties have been determined allowing prognostication for the increase of the thermal fatigue crack length under the conditions of water deslagging system usage. Another fact is also elicited - influence of tubes metal corrosive-erosive wear intensity on the process of cracking on their surface

INTRODUCTION

Utilisation of Estonian oil shale in power stations exceeds 20 mln tons a year. Estonian oil shale according to its quality is considered low quality fuel the calorific value of which makes 8-9 MJ/kg and the ash content of the working fuel is at the level of 45-65%. Estonian oil shale ash contains in considerable amounts calcium oxide (CaO containing is 45-55 %) and potassium oxide (K_2O containing is 6-7 %) and therefore has the intensive fouling and slagging tendency. The oil shale ash deposits on boiler heating surfaces have considerable corrosion activity in respect to the tubes' metal. This is explained by the fact first of all that in the oil shale ash there is chlorine (up to 1,0 %) that forms chlorides (among these with alkali metals). These components together with sulphates cause intensive fouling and high corrosive activity of Estonian oil shale ash. More detailed characteristics of Estonian oil shale ash and its fouling and corrosive properties are given in (1) and (2).

Estonian oil shale is burned in the boilers as a rule in the pulverized state alongside with dry ash removing. Consequently, annually about 10 mln tons of oil shale ash pass through boilers, the ash having the tendency to intensive fouling as well as high corrosive activity. Under such conditions long-time, effective and reliable working of the oil shale boilers can't be ensured without organizing an effective ,and reliable system of cleaning all heating surfaces.

An essential aspect of the matter when organizing cleaning of heating surfaces of the oil shale boiler is to put into operation cleaning of furnace screen surfaces. It should be borne in mind that the temperature of the metal of the screen tubes is relativly low (that is, metal's temperature is substantially lower permitted limits in accordance with high-temperature strength and high-temperature corrosion) and therefore there can be used highly intonsivo methods of cleaning withaut causing an essential damage to the metal of the tubes. This allows to increase to the maximum the heat transfer of the screens and thus reduce the temperature of the combustion gases in the convective superheater and reheater sections. Consequently effective deslagging of the furnace screens makes it possible to lighten the working conditions of th convective heating surfaces working under harder conditions both in high-temperature strength and corrosion.

It has been pointed out due to the results of numerous researches that the most radical and effective method of deslagging of furnace screens in case of their intensive fouling is on-load water-jet deslagging (3,4).

In the publications dedicated to the problems of on-load water-jet deslagging of boilers' heating surfaces it is noted that on achieving high cleaning effectiveness there is a danger of damaging the metal of the tubes. This danger is connected with great extra thermal stresses in the metal of tubes due to thermal shocks in the cleaning cycles. Up to the present time besides the research in thermal effectivness of deslagging, the research in influence of on-load water-jet deslagging on wear, structure and mechanical qualities of some boiler steels has been carried out. In some papers regularities of thermal cracking are also examined without any regard for the influence of corrosive-erosive wear on that process (5,6).

In the very paper there have been given the reults of the investigation of regular periodical usage of on-load water-jet deslagging on thermal fatigue cracking of screen tubes surface made of steel 12Cr1MoV under the conditions of burning Estonian oil shale.

EXPERIMENTAL INVESTIGATION

Experimental research has been carried out in the pulverized oil-shale-fired boiler steam output of 640 t/h (steam pressure 13,8/2,2 MPa and temperature 535/535°C) under actual operation conditions. This is a double-block boiler with natural irculation having a furnace chamber with cross-section dimensions of 8650x15000 mm and frontal 2-row located burners. The front screen of the furnace is made as radiation superheater with 12Cr1MoV steel tubes the diameter being 42 mm and wall thickness 4,5 mm.

The cleaning of the furnace screens is carried out by 4 devices of water deslagging (sootblowers) that are located by one on each side of the furnace. Water sootblowers have a nozzle with the diameter of 20 mm, water pressure before the nozzle being 0,30-0,35 MPa, angular velocity of the nozzle turning in horizontal plane being 0,42 rad/s and in the vertical plane 0,007 rad/s. This method of putting into an operation deslagging of radiation heating surfaces ensures the period of contact of water jet with the tube surface for no more than 0,3 sec and the maximum value of temperature drop on the outer surface of tubes being 120-150 degrees. The thermal stresses caused by this conditions have maximum value of 300-350 MPa. Water deslagging of the radiation superheater into which the experimental tubes were mounted-in to investigate corrosive-erosive wear and thermal fatigue cracking was carried out 3 times a week with an average period between cleaning cycles of 56 hours. The other 3 sides of furnace chamber with water walls which have substantially lower tubes' metal temperature were cleaned by the similar water sootblowers 2-3 times a day. A more detailed description of methods of testing and working conditions of the experimental mounted-in tubes is given in (4).

For the investigation on thermal fatigue cracking 5 tubes were chosen that worked under similar conditions for different period of time. Out of tested tubes specimens were made to study the regularities of thermal fatigue cracking. Basic characteristics of the experimental material are given in Table 1.

Table 1. BASIC DATA FOR THERMAL FATIGUE CRACK INVESTIGATION

Duration of testing, hours	Number of cleaning cycles	Number of examined specimens	Number of cracks total	Number of cracks fire-side semiperimeter
10921	195	26	828	494
19532	349	26	1723	1352
28984	518	27	910	645
39905	713	33	1152	996
Total		112	4613	3487

On the specimens all the cracks present were measured, for each crack two parameters were determined - the length (depth) and the location (angle) of the crack respect to fixed position (see legend in Figure 1). When processing the data the sample of the crack length was divided according to recommendations from (7) into intervals with the width of 0,01 mm. For each tube (with various number of cleaning cycles) the following characteristics were determined: average length of cracks, mean-square deviation of the samples, dispersion, coefficient of variation coefficient of skewness, excess and some other statistics. For each interval general number of cracks, relative frequency (i.e. number of cracks in the interval divided to total number of cracks), cumulative frequency (i.e. part of all cracks having the length less than upper limit of the considered interval) were determined. Having the data of measurements there were determined sampling density distribution function of cracks around the perimeter of tubes (see Figure 1) and according to the length of cracks (see Figure 2).

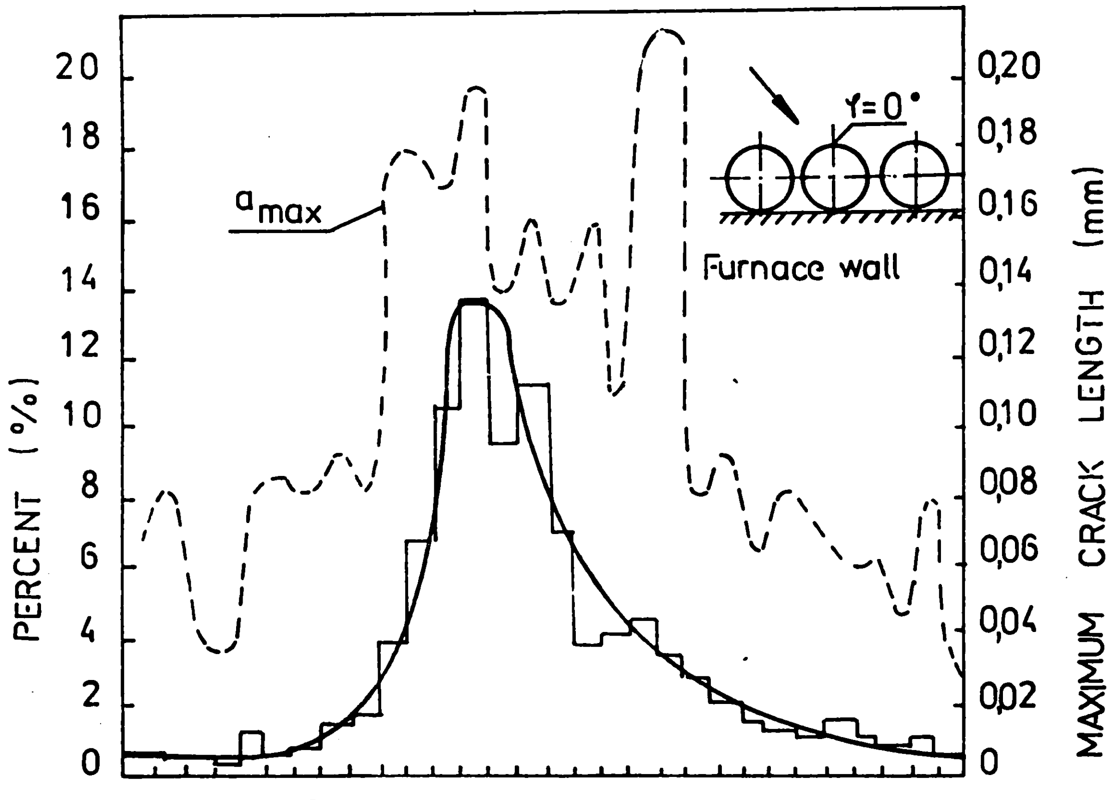

Fig.1. Thermal fatigue cracks' frequency and maximum crack depth distributions round the perimeter of tubes after 39905 hours of exploitation.

Out of presented in Table 1 and Figure 1 data it is evident most cracks appear on the fire-side semiperimeter of the tubes being under the influence of water-jets. The percentage of cracks on the fire-side semiperimeter of tubes in the course of time increases from 60% after 11.000 hours of work to 86% after 40.000 hours of work. Out of Figure 1 it is obvious that maximum crack length on the fire-side semiperimeter essentially exceeds maximum length of cracks on the back-side semiperimeter of the tube.

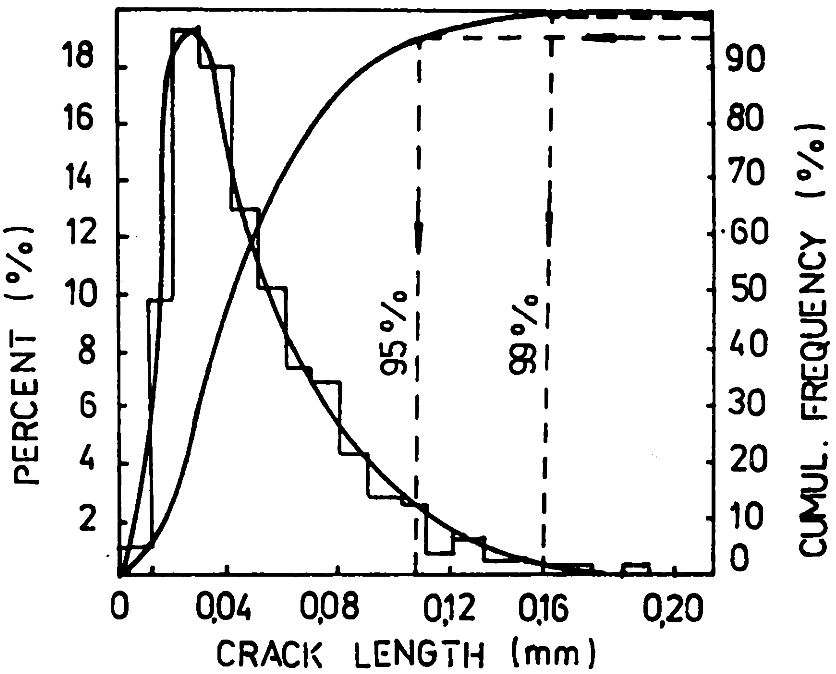

Fig.2. Dependence of the fatigue crack frequency on the crack depth after 28984 hours of exploitation.

The results of the calculations show that the distribution of cracks according to its length does not submit to normal distribution (i.e. coefficient of variation exceeds the value of 0,33, corresponding to normal distribution). Obtained coefficient of skewness points to the fact that all the tubes are observed to have left-side distribution of the length of cracks. With the increase of working time of tubes (number of cleaning cycles) there is a decrease of coefficient of skewness of distribution and consequently there takes place redistribution of relative frequency of cracks with different length. But despite the increase of relative percentage of the deeper cracks, in due course of time asymmetry of the distribution remains and the short cracks relatively prevail in number.

It follows from the obtained data that the distribution of cracks according to its depth conforms to the logarithmico-normal distribution and is described by equation

$$D(a) = \{1+ \mathrm{erf}[\ \ln((a/d)^m)/\sqrt{2}]\}/2 \qquad (1)$$

where D(a) is the percentage of those cracks present of less than the indicated depth a, %, d is the median of distribution i.e. the depth of the cracks corresponding to D=50%, m is a coefficient of homogeneity of distribution (angular coefficient of straight line of distribution in the logarithmico-normal coordinates).

As an example in Figure 3 the distribution of the depth of cracks on the outer surface of the 12Cr1MoV steel screen tube after 28.984 hours of work is expressed in logarithmico-normal coordinates.

On the basis of processing all experimental material relationships were found making it possible to predict the depth of thermal fatigue cracks depending on the number of cleaning cycles and the given reliability level. When predicting the length of cracks it is advisable

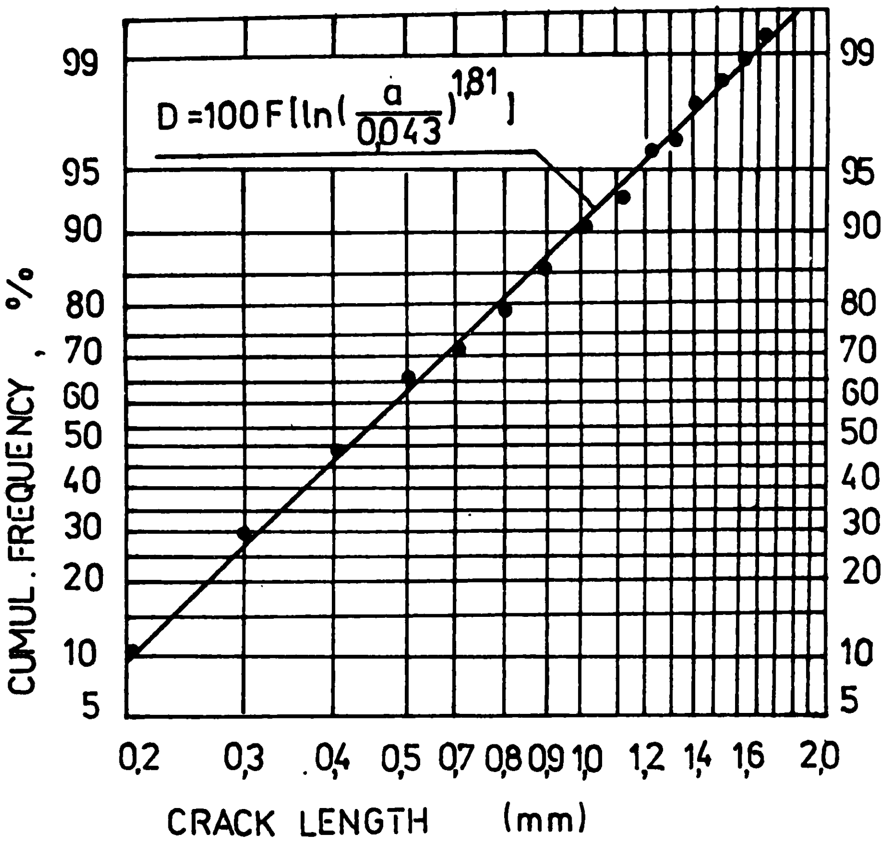

Fig.3. The sampling distribution function of cracks' cumulative frequency (after 28984 hours of exploitation).

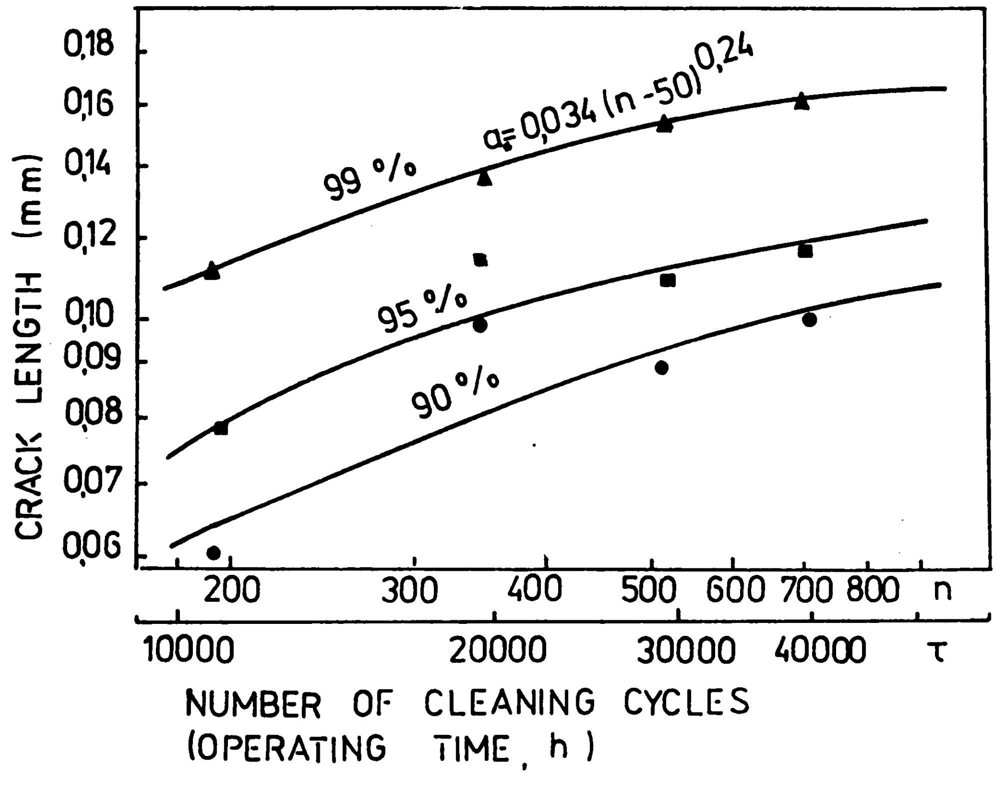

Fig.4. Dependence of thermal fatigue crack depth on number of cleaning cycles (operating time) and reliability level.

to take the level of reliability for 99% (see Figure 4). In this case factor of safety can be taken for 1,3 when calculating both corrosion and cracking whereas ratio of maximum depth of cracks to the depth corresponding to reliability of 99% makes after different number of cleaning cycles a_{max}/a_{99}=1,24-1,36. Thus, the length of the cracks depending on the number of cleaning cycles is determined by the following equation

$$a = 0,034\ (n - 50)^{0.24} \qquad (2)$$

The problem of maximum possible crack length is also of interest. The analysis of the experimental data shows that the presence and dimensions of cracks are determined by two factors - rate of high-temperature corrosion of tubes' metal and crack growth rate in a tube wall. Under conditions when there is no corrosion of metal the maximum length of cracks is determined by the level of thermal stresses. While water deslagging takes place thermal stresses have the maximum value on the outer surface of tubes and rapidly decrease in the tube wall. The distance on the outer surface of the tube on which the value of stresses becomes below the certain sufficient level, i.e. lower such a value of stress which is sufficient for the growth of cracks determines the maximum possible depth of cracks.

Under simultaneous processes of crack growth and high-temperature corrosion that are characteristic for oil-shale-fired boilers maximum length of cracks is determined by another condition - the maximum length is achieved at the time when rates of corrosion and crack growth become equal i.e. when the condition da/dn=ds/dn is satisfied. It is a well-known fact that when the temperature of metal rises the rate of corrosion increases and hence, the equality of the rates of these two processes is achieved formerly. Another thing is obvious also that in such a case there exists maximum temperature above which the existence of thermal fatigue cracks becomes impossible. It is evident that for each level of thermal stresses there exists its owh maximum temperature, and the higher the stresses are, the higher that temperature becomes.

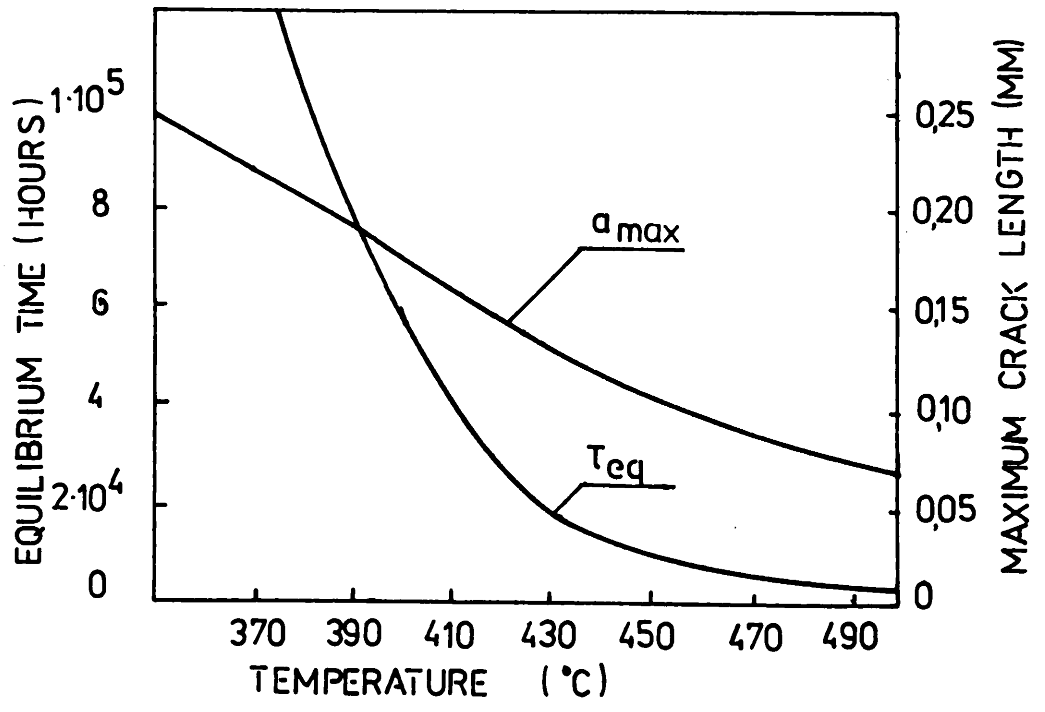

Fig.5. Maximum possible crack depth and corresponding equilibrium time in dependence on tube's metal pre-quench temperature.

In Figure 5 there is given a calculated dependency of time in achieving equal rates (equilibrium time) of high-temperature corrosion and growth of the depth of cracks on the tubes' metal temperature when burning Estonian oil shale. There is also given a dependency of corresponding maximum possible depth of cracks on the temperature of metal. The presented dependencies explain why on the surface of convective superheaters of oil-shale-fired boilers having the temperature of metal over 500°C under the on-load water-jet cleaning conditions there are no thermal fatigue cracks being formed In accordance with these conclusions also is a fact, that on the outer surface of tubes made from the austenitic steel 12Cr18Ni12Ti rate of high-temperature corrosion of which is about 5 times lower than that for 12Cr1MoV steel thermal fatigue cracks were formed in the similar conditions of water-jet deslagging (convective superheater).

Finally, as it was pointed out using of the on-load water-jet cleaning of boilers' heating surfaces is really connected with an initiation and development of the thermal fatigue cracks on their surfaces. But on the basis of special investigations the optimal parameters of cleaning regime can be determined and so using of such a method for cleaning of heating surfaces is perfectly safe and effective.

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