MICROSCOPICAL ANALYSIS AND CREEP BEHAVIOUR EXAMINATION APPLIED TO STEAM LINES IN POWER STATION EQUIPMENT

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Aplicarea metodelor microscopice de analiză la materialul metalic al tubulaturii de abur viu al echipamentului centralelor energetice în cursul funcţionării pe termen lung la temperaturi înalte constituie o modalitate utilă de prognoză a duratei de viaţă şi de creştere a fiabilităţii în condiţii de fluaj. Metodele specifice de analiză metalografică discutate şi aplicate în prezenta lucrare s-au dovedit a da rezultate aflate în bună concordanţă cu cele obţinute prin evaluarea comportării la fluaj.

Applying microscopical examination to the metallic material of which the steam lines in power station equipment is made of represents a useful tool for predicting the life time and for increasing the reliability of components subject to long term creep stresses at high temperature. The specific metallographic methods discussed and applied in this papers have proved to be in good agreement with the results obtained by creep evaluation.

Keywords: microstructural analysis, creep behaviour, steam line, heat exchanger pipe

Introduction

From the view point of the modern strategy of energetic politics regarding the human life standard, the production ensemble improvement, transport and consumption of the thermal energy represents a priority.

Also, the investment effort for the preservation of the same structure of the power production for the next 30 years, offers the possibility for the research to develop on the domain of the regeneration sources.

Thanks to the ingravescence of the environment global problems, climate changes and natural resources extension who drove to the issues complexity related to the production, transport and energy consumption, the energy politics is centered on minimizing the impact of the environment and

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development of a durable power system, activities who imply among others the increase of the power efficiency and the power logistics' competitivity.

A district heating power station in which the steam turbine produces both electrical and thermal energy may be in one of the following states during a period of 8760 hours/year: in function, in breakdown stopping, in programmed stopping, in static reserve. To improve the energy availability and the power station reliability one has to evaluate the condition of the metallic material of which the components are made and on this basis to predict their life time.

The metallic components of a district heating power station such as the steam lines and the heat exchanger equipment have a strong influence on the thermodynamic yield.

Two ways are available for predicting the life time of the steam lines:

(i) by following the evolution in time of the wall thickness and outer diameter of the steam pipe;

(ii) by carrying out microstructural analyses on the metallic material intended to establish the degree of spheroidization of the secondary phase in the steel of which the steam lines are made of.

Both ways have been applied in this paper and the consistency of the two types of results compared.

1. Materials and Methods

Predicting the life time by measuring the outer diameter of the steam lines is actually a method of long time evaluation for the main mechanical stress to which the steam lines are subject, namely the creep stress.

The remanent creep strains are evaluated by carrying out periodic measurements of the outer diameter according to accepted technical instructions. The exact locations in which the measurements are made are indicated by marks installed when the equipment was put in function and specified in the technical documentation of the steam boiler. The time space between two measurements is established at about 30% of the designed function time, but not exceeding 30000 hours in conditions of a normal evolution of the creep rate.

In order to diminish the costs for replacing equipment nowadays the examination of the power station equipment components is mainly focused on non-destructive periodic control by methods such as ultra-sound defectoscopy, penetrating liquids defectoscopy, magnetic powder defectoscopy, microstructural examination on extracted replicas (foils).

2. Results and Discussion

A. Concerning the steam lines creep behaviour

The creep behaviour of a steam line is generally evaluated in the stress raiser regions. Such a zone is reprezented by the ф273x38mm elbow that we have examined after 60000 hours in function at nominal parameters namely 19,2MPa pressure and 540°C temperature. Both microstructural analyses and creep remanent stress measurements have been carried out.

The chemical composition of the steel from which the examined steam-line was made of is given in Table 1 (steel 12CrMoV3).

Table 1

Chemical composition of steel 12CrMoV3 according to the Romanian standard STAS 8184-87

Symbol	Chemical composition [wgt%]								
	C	Mn	Si	Cr	Mo	P	S	Al	Other elements
12CrMoV3	0.08 … 0.15	0.40 … 0.70	0.17 … 0.37	0.90 … 1.20	0.25 … 0.35	max. 0.030	max. 0.025	0.015 … 0.045	V=0.15…0.30

The microscopic examination has been performed at room temperature on special prepared areas in the above mentioned elbow zone (Fig.1a and Fig.1b).

Mechanical polishing, electrolytic polishing and nital 2% etching have been applied to prepare the selected area for metallographic analysis. STRUERS type foils have been pressed on and stripped from the prepared area. The microstructural relief inprinted on the foil was examined by means of a Neophot optical microscope (Fig.1c and Fig.1d).

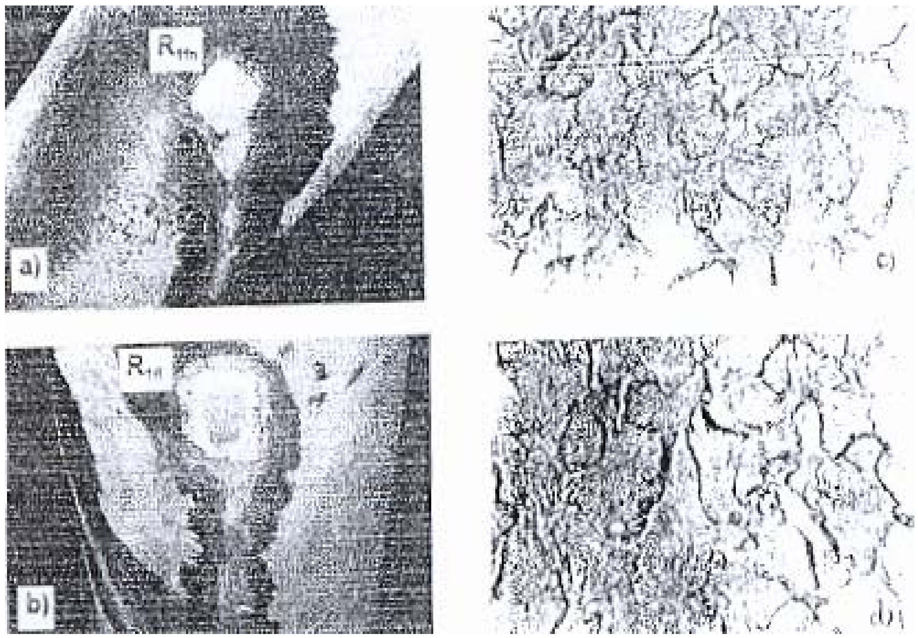

Fig.1 Metallographic analysis on the elbow of a live steam pipe
a) macrograph of the investigated area on the neutral fiber R_{1fn} of the elbow;
b) macrograph of the investigated area on the stretched fiber R_{1fi} of the elbow;
c) optical micrograph of the area on the neutral fiber of the elbow, 400:1;
d) optical micrograph of the area on the stretched fiber of the elbow, 400:1.

As put in evidence in the micrographs in Fig.1c, Fig.1d the microstructure consists of low alloy ferrite associated with alloy cementite finely dispersed in the ferrite matrix. Because the secondary phase exhibits a slight grain boundary precipitation and spheroidization tendency the structure has been ascribed to class 1 according to creep specifications, namely a slightly modified structure not containing creep porosity. Up to the examination moment no simple recrystallization processes and hence no grain growth phenomena responsible of an embrittlening tendency have manifested themselves. The grain size is fine being evaluated to a value 7 for the grain size index.

The above mentioned procedure for carrying out a non-destructive metallographic examination is easy to be applied whenever the energetic equipment is in a stopping period. However it cannot be applied to thin wall pipes(such as thin heat exchanger pipes). One also has to take into consideration the fact that the method gives microstructural information only on the defects lying close to the surface.

The remanent creep strain have evaluated by carrying out outer diameter measurements in the same locations that were specified for the metallographic examination. The results are presented in Table 2.

Table 2

Remanent creep strain results on a live steam pipe elbow

Pipe zone	Strain [%]					
	After 30000 hours in function			After 60000 hours in function		
	Neutral fiber	Streched fiber	Average	Neutral fiber	Streched fiber	Average
Elbow	0	0.086	0.043	0.014	0.150	0.082

The results in Table 2 point to a normal creep phenomenon in the elbow region of the investigated live steam line. Because the maximum admitted value of 0.8% for the remanent creep strain was not reached, one may conclude that there is no need to reiterate the outer diameter measurements sooner than a 30000 hours time elapse.

B. Concerning the creep behaviour for heat exchanger elements

Different criteria are adopted for predicting the life time for various categories of heat exchanger elements, namely:

- steaming device vaporizers and feedwater-heater economizers are affected by whatever modification in the feeding water chemistry and furnace running; on this account they are analyzed on corrosion criteria;
- superheaters are analyzed according to time-temperature-mechanical stress creep criteria, because they work at a higher temperature than other heat exchanger elements.

Both categories of heat exchanger elements consist of pipes of smaller diameter than steam lines. If the evolution in time of outer diameter and wall thickness is carried out one may evaluate the degree of corrosion or one may eventually detect increases in diameter that indicate the beginning of a type of damage produced by long time running at high temperature.

Actually it is very difficult to perform non-destructive outer diameter measurements on accont of the intricate geometrical configuration of heat exchanger devices.

It is far easier to perform metallographic analysis on specially cut samples. This method also offers the possibility to examine the material both in transverse cross-section and in longitudinal cross-section, and so one is able to obtain two different type of structural information. On the transverse cross-section one can evaluate the creep damage class and the grain size, whilst in longitudinal cross-section one can evaluate the quality compliance as far as the banded structure is concerned.

On account of the costs involved in replacing the cut pipes required for obtaining the metallographic samples, very seldom this method is applied in view of failure prevention. On the contrary the method is frequently applied in the framework of technical expertise programmes intended to establish the failure causes of heat exchanger pipes.

The chemical composition of the steel from which the examined heat exchanger pipe was made of is given in Table 3 (the Russian steel 12H1MF).

Table 3

Chemical composition of steel 12H1MF (according to Russian standards)

Chemical composition [%]	C	Mn	Si	Cr	Mo	V	Ni	P	S	Cu
Sample cut from pipe	0.14	0.49	0.23	0.96	0.27	0.19	0.06	0.012	0.007	0.07
According to standard GOST 20072-74	0.08 … 0.15	0.40 … 0.70	0.17 … 0.37	0.90 … 1.20	0.25 … 0.35	0.15 … 0.30	max. 0.30	max. 0.030	max. 0.025	-

Fig. 2 gives the results of the qualitative metallographic examination on a sample cut from a ф32x6mm heat exchanger pipe that has been in function for about 190000 hours at temperatures in the range 485°C (input) and 535°C (output).

As clearly put in evidence in Fig.2 the heat exchanger pipe has been broken in the elbow region that works as a stress raiser (Fig.2a).

The longitudinal failure in Fig.2b exhibits prominent crystalline grains and thick lips, whilst the microstructure in Fig.2c shows a high degree of spheroidization of the secondary phase but no compacity defects such as pores and microcracks. All thesese structural features point to a typical behaviour of a material that has been subject to a long term overheating.

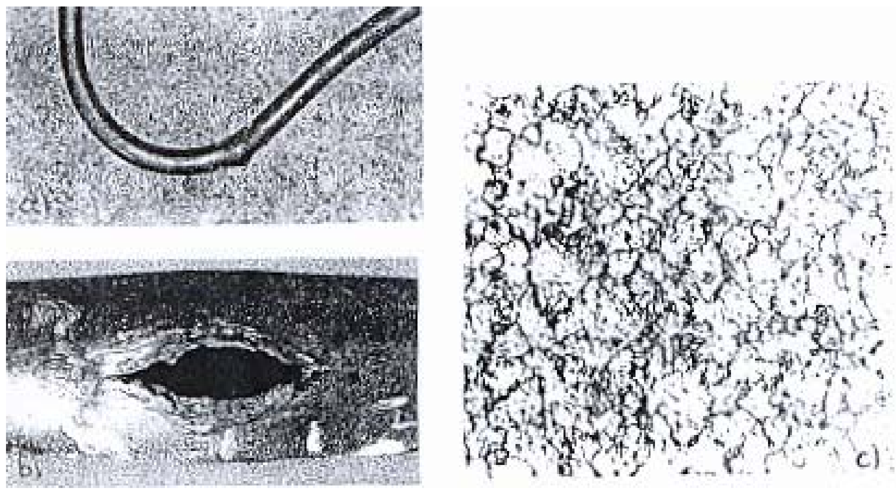

Fig.2 Metallographic analysis on a heat exchanger pipe broken in service on account of overheating during long term function at high temperature

a) failure region;
b) longitudinal failure in the material;
c) micrograph of the pipe material in undamaged zone; transverse cross section, 400:1.

So the investigation methods we have applied can give information on all specific phenomena that may occur in service such as erosion zones location, high and low temperature corrosion, overheating and internal grain boundary oxidation.

Conclusions

1. The life time of the metallic components of district heating power station may be increased and the exploitation costs decreased if analysis and prognosis techniques are applied.

2. The metallographic analysis of the district heating power stations components, though having its own limits is nevertheless a rapid and efficient method to establish the material condition during the long term exploitation.

3. The microstructural analysis applied in this specific field may be carried out either in a non-destructive manner on extracted replicas or in a destructive manner on samples cut from the material. The former method can be applied only on certain components and gives information only on surface defects. The latter method gives complete information on the material microstructure but when applied to energetic components involves high costs.

4. By following the material behaviour during long term function one may take decision on programmed replacing of the pipes that would avoid failures and ensure a continuous delivery of energy for the customers.

REFERENCES

1. *N.Popescu, R. Şaban, D. Bunea, I. Pencea,* Material Science for Mechanical Engineering, vol.2 Commercial metallic, non-metallic and Composite materials (in Romanian), Fair Partners Publishing House, Bucharest, 1999;
2. *Mirela Tinică***,** Specified aspects of the microstructural analysis applied to diagnosis of power station subanssemblies, Technical-scientific bulletin ICEMENERG, p.66-69, ICEMENERG Publishing House, Bucharest, 2004;
3. *** Investigation works on power station equipment ICEMENERG, 2002-2005;
4. *** Standards;
5. *H. Schumann,* Physical metallurgy (in Romanian), Tehnical Publishing House, Bucharest, 1962;
6. *Şt. Mantea, N.Geru, T. Dulămiță, M. Rădulescu,* Physical metallurgy (in Romanian), Tehnical Publishing House, Bucharest, 1970;
7. *M. Aldea*, Steam boilers and pressurized reccipients (in Romanian), Tehnical Publishing House, Bucharest, 1982.