Archives of Materials Science and Engineering
Volume 34
Issue 1
November 2008
Pages 43-47
International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Factors determining the durability of steam superheater chambers

K. Mutwil*, J. Lisok
Department of Process Modelling and Medical Engineering, Faculty of Materials Science and Metallurgy, Silesian University of Technology, ul. Krasińskiego 8, 40-019 Katowice, Poland
* Corresponding author: E-mail address: kazimierz.mutwil@polsl.pl

Received 13.08.2008; published in revised form 01.11.2008

ABSTRACT

Purpose: The paper presents the results of calculations of effort for the material of selected superheater chambers' constructional systems in unsteady operation conditions.

Design/methodology/approach: In model tests, the influence was analysed of internal pressure and temperature gradient in the chamber wall on the distribution and value of stress . In the calculations, the process of hot start-up of a boiler was simulated, which was accompanied by short thermal shock induced by rapid cooling of the chamber inner wall.

Findings: The random nature of thermal shock, which in the industrial practice may occur in any row and to any number of coil pipes, determines the value of maximal stress and the area of its occurrence. It has a significant influence on the possibility of forecasting the durability of chambers in working conditions.

Research limitations/implications: The research has evidenced a link between the method of forcing thermal shock and the value of maximal stress in the area of bridges.

Practical implications: The research has demonstrated the existence of connection between the way of forcing thermal shock and the stress value which, depending on the variant of cooling the chamber, ranges between 150-370 MPa. These results are very important to the industry connected with the structure of pipelines.

Originality/value: It was found that the primary reason for the superheater chamber damage, leading to crack formation, are thermal shocks. A link has been shown between the method of forcing the thermal shock and the value of maximal stress in the zone of bridges.

Keywords: The outlet chamber of steam superheater; Intermediate pipelines; Attemperators; A discrete superheater model; Nal systems in unsteady operation conditions

METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

In superheater chambers, the factor determining the material effort are loads coming from external forces, internal pressure and interactions caused by a non-uniform distribution of temperature fields and its gradient [1-6].

Mosts superheater chambers are exposed to the action of a variable temperature during shut-downs and start-ups of a power generation unit, frequently of thermal shock nature, which leads to generating cracks in thermal fatigue conditions.

Defects of chambers appear on their inner surfaces and usually, they are located on the edges of holes, within the area of bridges (Fig. 1). Figs. 2 and 3 present changes in the microstructure of the material and morphology of cracks detected in the area of bridges, based on the observation of replicas. The observed intercrystalline cracking systems do not exhibit a creep nature of their initiation. At the same time, the system of coagulated precipitates of carbides on grain boundaries (Fig. 3) shows a considerable degree of degradation of the material's initial structure.

The processes of degradation of the superheater chamber material are accompanied by creep processes. Creep, as the effect of operating conditions above the threshold temperature, is often accelerated since in practice, the analytical temperature is often exceeded [7-9]. Chambers' durability is determined with the value of stresses in areas under highest effort. For a constructor, the knowledge on dependencies between values which load the facility and value of stress in the criterion areas is vital. Engineering procedures contained in the regulations of UDT, PN, TRD, etc., are usually used for calculating the maximal stresses for complex facilities.

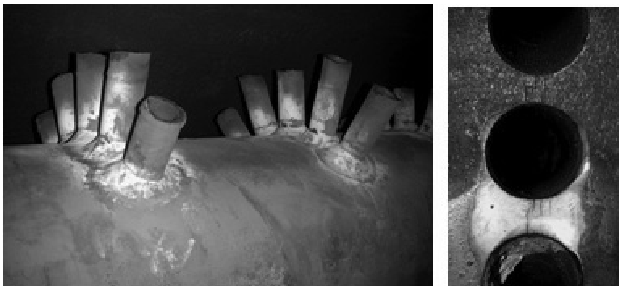


Fig. 1. Fragment of a superheater chamber after its long-term service

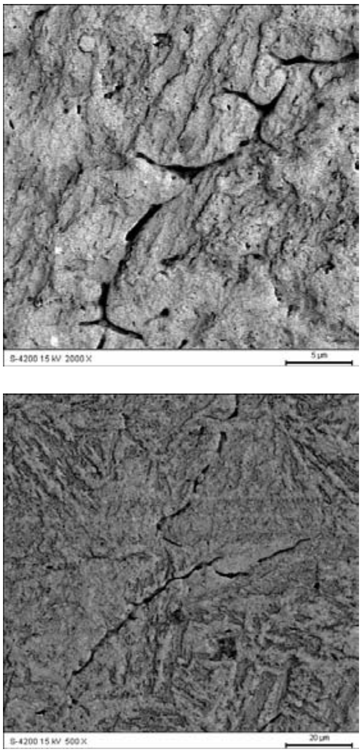


Fig. 2. Crack system in the chamber area of bridges

Simplified models of real facilities are used in such calculations, without taking into account their specificity. In case of T-pipes, neither their detailed geometry (radiuses, bevelling, undercuts), nor the influence of a pipeline on its lines is taken into account. However, the calculation procedures for superheater chambers do not take into consideration, among other things, the impact of coil pipes on the chamber, rigidity of connecting pipelines, the method of supporting the chamber, the number and location of supports, the deadweight, and detailed features of its geometry. The only method, which would allow taking into consideration all significant factors conditioning the effort of the facility, are numerical calculations, based on FEM or BEM algorithms [10-11]. Stress distribution in the superheater chamber was analysed in the in the study with taking into consideration factors which are not contained in calculation procedures.

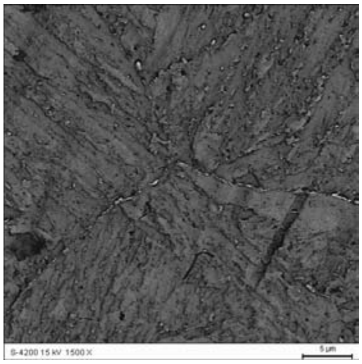


Fig. 3. Carbide precipitations on grain boundaries

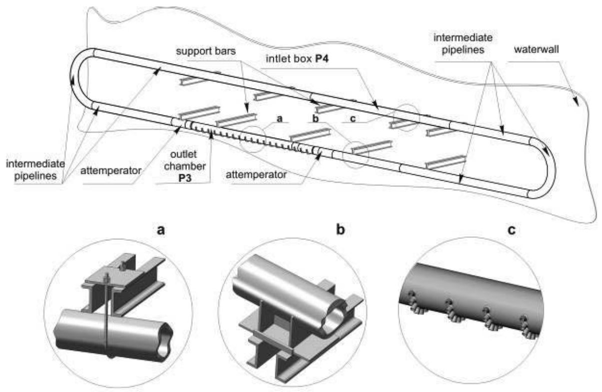
2. Object of research

The object of research was the outlet chamber of steam superheater P3 [7]. The analysed chamber, produced of X20CrM0V12 steel is a thick-walled pipe of external diameter ∅342 and wall thickness 46mm. The chamber is connected with coil pipes of diameters ∅44.5 x 5.6. The chamber and coil pipes are connected with ferrules of diameters ∅44.5×6.5. The outlet chamber of superheater P3, together with the inlet box of superheater P4, intermediate pipelines and attemperators, forms a unit of superheater chambers. Geometric form, location of supports and principal geometrical features of the superheater chamber unit is shown in Fig. 4.

3. Investigation of the reasons for cracking of steam superheater p3 chamber

Calculations of stress distribution in the chamber were performed on a discrete superheater model, taking its geometrical and material features into consideration. Superheater chambers together with intermediate pipelines and attemperators were modeled as hexahedral elements [12-13]. In order to reduce the size of the model, a fragment of a P3 chamber, containing 4 rows of coil pipes was taken into consideration in the analyses (Fig. 5).

Mechanical properties and pipes' diameters of the individual system's elements were taken into consideration in the calculations. Supports of superheater chamber unit in the model were simulated with moveable and elastic supports as it is presented in Fig. 6.



Part of a unit	Dimension	Material
Outlet chamber	M342x46	X20CrMoV121
Attemperator	M355,6x55	10CrMo910
Intermediate pipelines	M233,6x50	10H2M 10CrMo910
Inlet box	M233,6x45	10H2M

Fig. 4. Diagram of steam superheater chamber unit

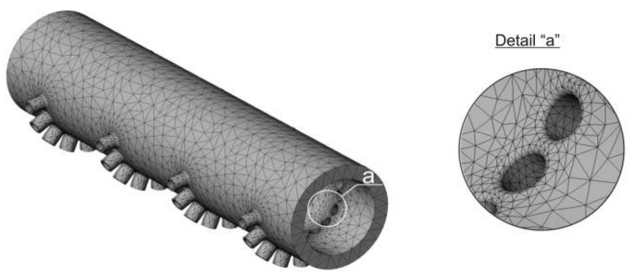


Fig. 5. Model of a fragment of a superheater chamber

The rigidity of the chamber unit influencing the value of stresses in the chamber part being examined was taken into consideration (Fig. 5), when analysing the whole chamber system. Results of the calculation in a form of bitmaps were shown only for a selected part of the chamber.

Factors, which condition the durability of analysed object, are loads caused by internal pressure changes and difference in temperatures on the wall's thickness during power unit's shut-downs and start-ups.

Using numerical calculations, the influence of each of these factors on the stress value and location of the areas under highest effort was analysed in the paper. Figure 7 shows the results of calculations of stress distribution on the chamber inner surface, with taking into account the impact only of the internal pressure.

As a result of the pressure's impact, the areas under highest effort occur at the edge of holes in axial direction of the chamber (Fig. 7). However, in the circumferential direction (area of bridges), an relieving effect of the serial notch system, consisting of the holes of ferrules [12, 14], is observed. In this connection, stresses induced by the internal pressure in the area of bridges reach lower values than stresses on the surface of chamber in the area between outlets of coil pipes. So, the internal pressure is not the factor which leads to generating cracks observed in the area of bridges. The presented results of calculations show that the cracking processes observed in the operating conditions (Figs. 1, 2) may be conditioned by the temperature gradient on the chamber wall's thickness.

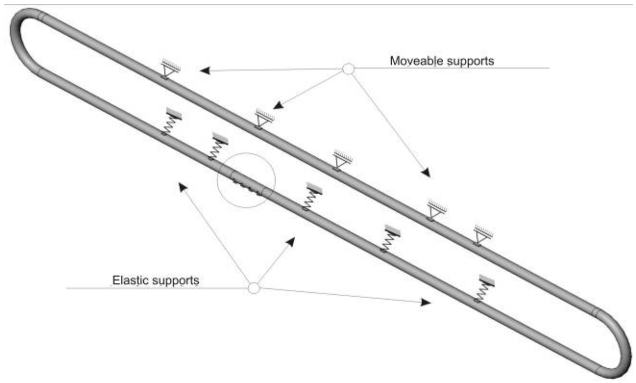


Fig. 6. Model of a steam superheater chamber unit

Fig. 7. Distribution of reduced stresses on the chamber inner surface induced by steam's pressure

During boiler start-up, incidents of local, rapid cooling of the inner surface of chamber are recorded. The reason of the observed "thermal shocks" may be inappropriate operation of attemperators or thrust of the steam condensate accumulated in lower parts of the coil pipes. A case of thermal shock, recorded in the boiler start-up conditions, is presented in Fig. 8.

In the model tests, the thermal shock was simulated through forcing a rapid decrease of the temperature on the inner surface of chamber according to W_2 curve, shown in Fig. 9.

Calculations of temperature distributions and distribution of the reduced stresses corresponding to them were conducted for a selected time t_2, corresponding to the maximal temperature gradient in the chamber wall during start-up of the boiler .

When performing numerical analyses, it is necessary to take into consideration that the recorded changes of temperature on the inner and outer surface of the chamber (Fig. 8) do not indicate the method of inducing the thermal shock. This shock could be induced by the flow of an agent cooling all the inner surface of the chamber or by thrust of the coolant from ferrules of coil pipes.

In case of the coolant thrust, the method of cooling is determined by the number of coil pipes through which it was thrust. At low number, cooling is of local nature, without any significant impact on cooling of the remaining part of the chamber. However, the thrust from several rows of ferrules influences significantly the conditions of heat exchange along the chamber length due to lowering of the temperature of close-to-wall layers through successive supply of a cool agent via successive rows of ferrules.

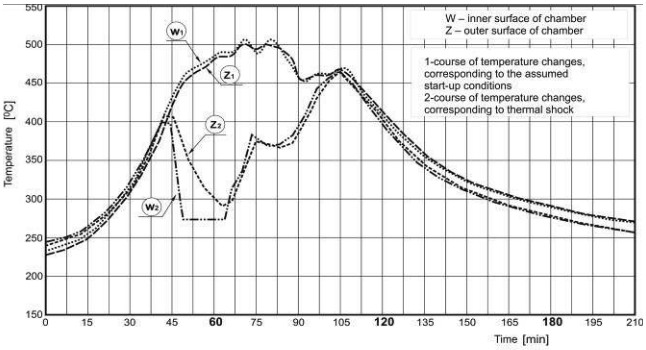


Fig. 8. Temperature changes recorded on the inner and outer surface of chamber during boiler start-up

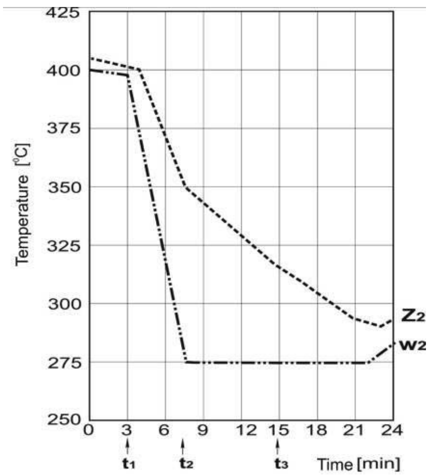


Fig. 9. Characteristics of thermal shock adopted for calculations

Results of numerical simulations of thermal shock induced by the thrust of a "loop water seal" through two adjacent coil pipes is shown in Fig. 10. It was assumed in the model that cooling takes place on the inner surface of each of ferrule and that the cooling agent thrust does not influence the change of temperature in the remaining chamber areas. The analyses were conducted, assuming the temperature changes as in Fig. 9. Stress distribution was determined within time t_2, representing 450 s from the start of cooling.

For the method of inducing thermal shock, assumed in the calculations, the areas of stress concentration are located in the area of bridges between the holes. The value of maximal stresses on the hole edge is 370 MPa and it is similar to the yield point of the chamber material, $R_{0.2/300C}$ = 390 MPa. Taking the foregoing into account, it is possible to assume that the main reason conditioning the durability of a chamber is a thrust of "loop water seals" causing local cooling of the chamber inner wall.

Fig. 10. Distribution of reduced stresses on the inner surface induced by a local cooling of the chamber

Stress distributions determined for an identical course of temperature change in time, with the assumption of loop water seal thrust through the whole row of coil pipes is shown in Fig. 11. For such method of inducing thermal shock, the value of maximal stress σ = 290 MPa is significantly lower in comparison with a case shown in Fig. 10.

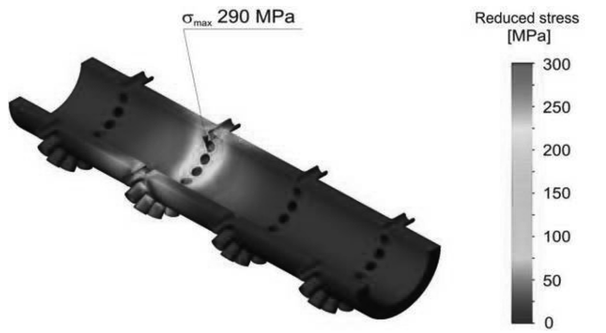


Fig. 11. Distribution of stresses on the chamber inner surface as a result of cooling through a row of coil pipes

Fig. 12 shows the result of calculations of a simulation of thermal shock induced by cooling of the whole inner surface of the chamber. The analyses were conducted for time t_2, assuming shock characteristic identical with that of a previous variant of calculations.

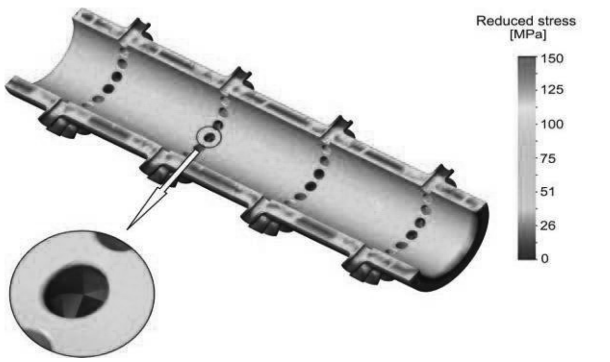


Fig. 12. Distribution of reduced stresses induced by cooling the whole inner surface of the chamber

Calculations for the assumed model exhibited stress concentration on the hole's edge ($\alpha_k \approx 2$ [14-15]) on a small area of bridge (Fig. 12). The determined area of stress concentration of a value ca. 150 MPa is located in the chamber crack area.

Stress of such value cannot condition the chamber durability, whereas in the situation of seal thrust from a considerable number of coil pipes, it will sum up with stresses induced by local thrust from individual ferrules, which may lead to intensification of the chamber crack process.

4. Discussion of research results

Distributions of reduced stresses in the superheater panel, induced by thermal shock in the conditions of an unsteady heat flow, reach (Figs. 10-12) maximal values in time t_2 = 450 s of a rapid cooling cycle of the chamber inner surface. The stresses are concentrated on edges of holes and in the area of bridges.

The calculations were performed with assuming for the chamber models identical characteristics of thermal shock recorded during one of boiler start-ups. The recorded temperature variability confirms the existence of thermal shock, but it contains information neither on its reasons nor on how the temperature change occurred. The research has demonstrated the existence of connection between the way of forcing thermal shock and the stress value which, depending on the variant of cooling the chamber, ranges between 150-370 MPa.

Thrust from several coil pipes or thrust from coil pipes located in distant rows is the reason of stress generation in the area of bridges, of values similar to the yield point of the material. In such case, due to the cyclic nature of the chamber cooling process, the areas of chambers under highest effort undergo degradation as a result of thermal and mechanical fatigue of a low-cycle nature [12].

However, if the whole inner surface of the chamber is cooled or the thrust is performed through the whole rows or coil pipes, the thermal stresses in bridges reach significantly lower values. In this case, despite stating thermal shock in the area of bridges, the course of damage processes will be less intense.

In the industrial practice, thermal shock may take place at random in any row and at any number of coil pipes, which has significant impact on the real conditions of heat exchange at the chamber length. The value of maximal stress and area of its occurrence in connection with that, will be characterized by considerably lower changeability, which significantly influences the possibility of forecasting chambers' durability in the working conditions.

Tests of stress distribution were conducted without taking into account the influence of pressure on chamber effort. During the start-up, pressure influences the global level of stress in the chamber, while in the area of bridges, a relieving effect occurrence of the serial notch system consisting of the holes of ferrules. The result is that the stresses induced by the internal pressure in the area of bridges reach lower values than stresses on the surface of chamber in areas between outlets of coil pipes.

5. Conclusions

1. Any damage to superheater chambers occurs on the inner surface and usually is located on the edges of holes in the area of bridges. The intercrystalline cracking systems observed do not exhibit a creep nature of their initiation.
2. Thermal shocks are the reason for generating maximal stresses in the area of bridges of superheater P3 chamber, which determines the cracking processes in these areas as a result of thermal fatigue of a low-cycle nature.
3. The research has evidenced a link between the method of forcing thermal shock and the value of maximal stress in the area of bridges.
4. The random nature of thermal shock, which in the industrial practice may occur in any row and to any number of coil pipes, determines the value of maximal stress and the area of its occurence. It has a significant influence on the possibility of forecasting the durability of chambers in working conditions.

References

[1] E. Zbroińska, J. Dobosiewicz, Damages of steam boilers' superheater header, Power Engineering 3 (1993) 97 (in Polish).

[2] J. Dobosiewicz, Superheater chambers deflection, Power Engineering 10 (1995) 459 (in Polish).

[3] S. Kocańda, Fatigue destruction of metals, WNT, Warsaw, 1978 (in Polish).

[4] J. Dietrych, S. Kocańda, W. Korewa, Fundamentals of machine construction, WNT, Warsaw, 1971 (in Polish).

[5] K. Mutwil, M. Cieśla, Estimation of superheater header strenuous in steady-state conditions of power boilers, Proceedings of the 7th Scientific International Conference „Computer Aided Engineering", Polanica Zdrój, 2004 (in Polish).

[6] A. Hernas, J. Dobrzański, Durability and destruction of boilers and steam turbines' elements, Silesian University Press, Gliwice, 2003 (in Polish).

[7] E. Rusiński, T. Smolnicki, J. Wyszyński, Numerical simulation of the effort of the second stage superheater header in the boilers of Power Plant 'Turów', Mechanical Review 5-6 (1999) 30-34 (in Polish).

[8] K. Mutwil, M. Cieśla, Constructional and operational conditions of steam superheater chambers cracking processes, Materials Engineering 28/6 (2007) 914-919 (in Polish).

[9] T. Wróblewski, A. Pepłowski, H. Górecki, Boiler equipments, PWN, Warsaw, 1970 (in Polish).

[10] A. Waynman, Modern state of the problem of hydrogen embitterment of metal of TPP thermo-mechanical equipment of pre-and overcritical parameters, Proceedings of the 3rd International Conference "Facture mechanics of materials and structural integrity", Lviv, 2004.

[11] C.C. Spyrakos, Finite Element Modeling in Engineering Practice, West Wirginia University Press, Morgantown, 1994.

[12] K. Mutwil, M. Cieśla, J. Okrajni, J. Lisok, Forecasting of residual durability of power industry objects by the use of numerical modeling, Surface Mining 50/4-5 (2008) 141-147 (in Polish).

[13] T. Hobler, Thermal motion and exchangers, WNT, Warsaw, 1956 (in Polish).

[14] A. Wocławski, Steels characteristics, Series D, Steels operating in elevated and reduced themperatures, Vol. 1, Part 2, Steels for power industry, Śląsk, Katowice, 1984 (in Polish).

[15] J. Czmochowski, A. Górski, A. Iluk, J. Wyszyński, Numerical strength analysis steam superheater of the power boiler, Proceedings of the 6th Scientific International Conference „Computer Aided Engineering", Polanica Zdrój, 2002 (in Polish).