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Analysis of End Crack in Boiler Tube

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Abstract: Boiler tube failures usually result in frequent forced outages, and ultimately in costly extended outages for major tubing replacement in a plant. There are several failure modes that may occur in a boiler tube, i.e. stress-corrosion cracking, pitting, water-side corrosion, fire-side corrosion, fatigue failure, overheating, dissimilar metal weld fatigue, mechanical fatigue and erosion. In this research the failure modes of boiler and its end cracks due to the dissimilar metal weld is analyzed. Hence data are collected and explored to determine the cause of failure and as a solution ceramic ferrule is suggested. The use of ceramic ferrule in boiler tube can eliminate the crack occurrence or delay the process due to thermal properties. The prevention of crack will reduce frequent maintenance and thus the cost of operation can be minimized.

Introduction

Power plant is a facility that transforms various energies into electricity or heat for useful purposes. Meanwhile, the energy input varies such as potential energy (Hydroelectric Power Plant), chemical energy (Gas Fired Power Plant), Solar Energy (Solar Power Plant), and fission or fusion energy (Nuclear Power Plant) [1]. The term "boiler" applies to a device that produces (1) steam for power, processing, or heating purposes; or (2) hot water for heating purposes or just hot water supply [2]. The main function of a boiler is to convert water to steam for the purpose of power generation. The body of the boiler is the pressure vessel and contains the fluid and it can be of water tube and fire tube type boiler. The tubes are made from unalloyed or low alloy steel by hot finished or cold finished and the hot finished tube can be heat treated to provide a uniform grain structure or ductility for severe forming operations or cold drawing[3]. Various factors like deficiency in design, fabrication, operating conditions, unsuitable materials selection [4-6] can lead to boiler failure.

In this investigation, the failed boiler tube specimen was collected from a gas fired power plant in Malaysia. The tubes are welded in the end to the wall of the boiler. Virtually all cracks occur at welded joints or at openings [7-8]. This is a frequent, costly and dangerous occurrence. The root cause is corrosion fatigue and the fatigue cycling is thermally driven. The thermal fluctuation that occurs is due to the slag and the change of operating conditions also creates alternating stresses. As a result the boiler tubes are subjected crack. The plant need to be overhauled for maintenance purpose due to the leak generated from the cracks [4]. The analysis is predominantly simulation based which focused mainly on the root cause of the failure of boiler tubes exposed to operating condition.

Methodology

Based on the availability of functions, information or details, convenience etc the simulation was carried out using several available software. In this analysis mainly 3 types of software were used in carrying out different type of task. Pro ENGINEER was used to do the drawing only whilst ALGOR did the simulation on mechanical and material testing and GAMBIT (Geometry and Mesh Building Intelligent Toolkit) and Fluent were used for temperature distribution simulation.

Results and Discussions

The end cracked boiler tube material was of BS 3059 carbon steel with diameter (Ø) and thickness (t) of 63.5mm, 3.6mm respectively. The steam flow was 15-30 tonne/h with steam pressure of 14 – 16 bar and temperature 120 ˚C. The visual examination revealed minute cracks at the welded zone and the SEM photograph of samples are given in Fig. 1.

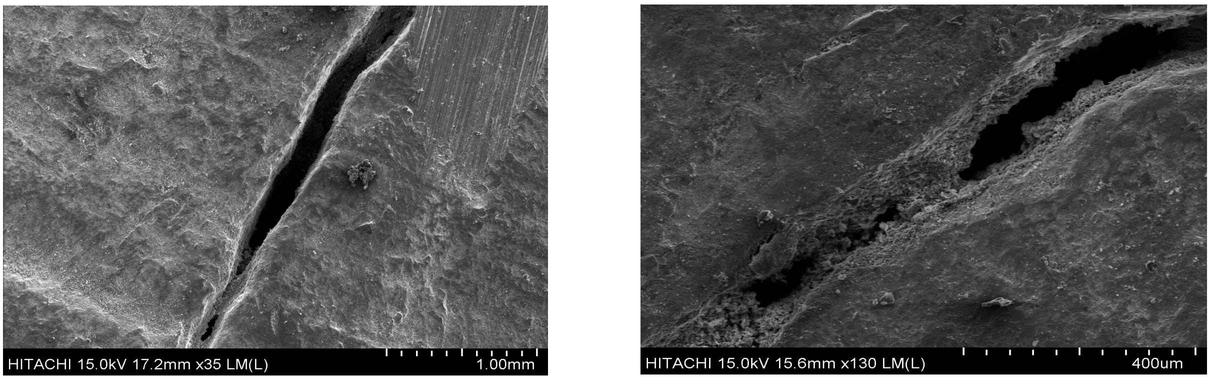

Fig. 1: SEM photograph of crack in boiler tube (a) sample 1 (b) sample 2

Thermal-Heat Flux Magnitude. The thermal heat transfer analysis was conducted by applying surface heat flux on the inner wall surface of the tube that will either supply heat or take away heat during the process. The vector option was then activated and the vector plot of the heat flow was displayed. Fig. 2 illustrates the heat flux magnitude along the boiler tube. The color contour best illustrates the heat distribution where red color has the maximum magnitude, 2.62E-14 J/mm^2 and purple has the lowest value of 1.014E-15 J/mm^2.

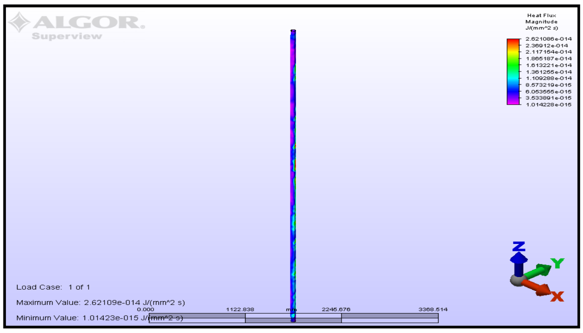

Fig. 2: Heat Flux distribution along the tube

Fig.3: Contour of total pressure in boiler tube

CFD Analysis

Modelling. Using GAMBIT, the boiler tube and its weld were drawn two dimensionally for the 2D analysis. The actual dimensions for the boiler tube were taken in 3D. For the ceramic ferrule, the top cylinder's outer radius is 0.06175m with about 5cm thickness and the lower cylinder has an outer radius of 0.02813m with a thickness of 0.5cm. The total length of the ferrule designed was of 10cm.

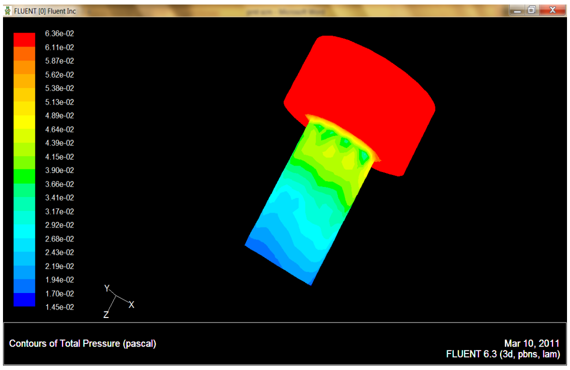

Fig. 4: Total pressure contour for ferrule

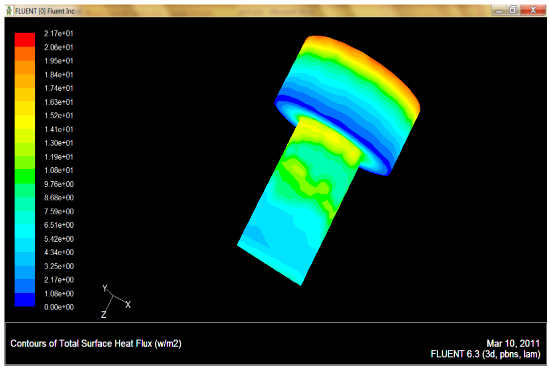

Fig. 5: Heat flux contour for ferrule

Mesh. The models were meshed in order to get a precise solution. Complex materials require tri/quad mesh while for simpler material, only quad mesh can be used. Boundary conditions were specified accordingly for each model. The modeled, meshed and labeled drawing was then exported to FLUENT as .msh file to analyze further.

The colour contours, vectors and residual plot were obtained from the FLUENT analysis. In heat transfer analysis it was observed that the pressure ranges from 1.18Pa to 8.23E-4Pa. The highest pressure is at the tube inlet area which is 1.18Pa; while at the outlet pressure is minimal. The pressure distribution is given in Figure 3. The analysis showed that heat flux was constant throughout the tube. There was also no radiation heat transfer. The total heat transfer rate is 1154886.4W across the boiler tube.

Ceramic (ZTA) ferrule was used in the analysis to prevent the end crack. The highest pressure is located at the inlet area of the ferrule which is within the range of 6.36E-2Pa to 1.45E-2Pa as presented in Fig. 4. However, it is much lower than the boiler tube inlet pressure. Hence, summarizing that the ceramic ferrule will be able to withstand the load and delay the fracture's occurrence. The highest heat flux value is 21.7 W/m^2 as can be seen from Fig. 5. Heat transfer rate at the inlet of the ceramic ferrule is 112.53W and a very low of total heat transfer rate is produced which is approximately zero. The theoretical characteristics of the ceramic ferrule (low thermal conductivity) are supported by the findings [9].

The input values of heat generation rate, heat flux, inlet temperature, material properties were taken from online sources to carry out simulation and CFD analysis. So there may be variations in results from the actual theory, however, it demonstrated a lower pressure and lower rate of heat transfer in the ceramic ferrule. The boiler tube material used in this investigation is the low carbon steel. The pressure generated is 1.18Pa at the inlet of the tube and the heat transfer rate is 1154086W which is much higher than the ceramic ferrule. The ceramic type used in this analysis is zirconia toughened alumina which generates a pressure of 6.32E-2Pa and transfer very little heat across it i.e. 112.53W. Table 1 below shows a comparison between both the materials. The ceramic ferrule can sustain both the pressure and heat load, thus can delay the fracture and prevents crack formation due to its great thermal properties.

Table 1: Comparison between the boiler tube and the ceramic ferrule

	Tube	Ferrule
Material	Low carbon steel	Zirconia toughened alumina
Pressure	1.18 Pa	6.32e-2 Pa
Heat transfer	1154086 W	112.53 W

Conclusion

The mode of failure for a boiler tube end crack was investigated and a ceramic ferrule is the suggested solution. The ferrule is to be fitted on to the inlet end of the tube to prevent thermal shock when hot flue gas enters the tube. Ceramic materials are chemically inert to almost all materials, however, it has the risk of fracture. Though, the design may contain flaws that can be further improvised for a better implication. The application of the ceramic ferrule on a boiler tube can be used to eliminate crack occurrence, or at least delay the crack occurrence.

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