Short communication

An incident investigation on stub tube at high temperature reheater outlet header region of a power plant

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\begin{abstract}
1. Introduction

The investigation was carried out following an incident of a stub tube failure at high temperature reheater (HTRH) outlet header region of a boiler unit in Kapar Power Station Malaysia. Visual inspection and microscopic examination were carried out to evaluate the failure mechanism and the root cause. The failure was occurred on 24 February 2007. The failed SA213-T22 (2\%Cr–1 Mo steel) tube was located adjacent to dissimilar weld joint which connects to HTRH tube made of Inconel/Incoloy\textsuperscript{C} 800. Schematic location of the failed tube and condition of the HTRH outlet header compartment in the boiler unit are shown in Fig. 1. Prior to the failure, the boiler unit had been in service for around 151,975 h. The last planned outage for preventive maintenance prior to failure was carried out in April 2006. The maintenance was involving welding works at the region. It was reported that utilization of crumpled papers by inserting into both tube ends for eliminating air flow from interrupting welding work was often used. Next, the boiler unit was returned into service and operating for around 5050 h since the last outage. The failed stub tube and HTRH tube have the same outer diameter of 50.8 mm and thickness of 3.8 mm. The chemical compositions of SA213-T22 [1] and Inconel/Incoloy\textsuperscript{C} 800 [2] are presented in Tables 1 and 2, respectively. The typical operating steam pressure of HTRH tubes as shown in Fig. 2, shows that the average operating pressure is 27.5 bar (2.75 MPa).

2. Visual inspections

The failed SA213-T22 tube was found to be rupture at the area next to the dissimilar weld joint (heat affected zone) connected to HTRH Inconel/Incoloy\textsuperscript{C} 800 tube. Fig. 3 shows a close-up of the ruptured region, the failed stub tube and the high

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temperature reheater outlet header. Blister is seen at the rupture region. The blister is usually caused by overheating and by loss of strength as a result of reduction in carbon content. The outer surface of Inconel/Incoloy® 800 tube which connects directly to the failed tube was found to have abnormal yellowish colour (Fig. 4) which indicated the sign of extreme high metal temperature operation. The failure had not occurred at the HTRH tube which was located in the hotter region of furnace flue gas flow path. However, it very significantly influenced the adjacent tube at the cooler region of the HTRH header compartment which was located away from the flue gas flow path.

Table 1
Chemical composition of SA213-T22 (wt.%) [1].

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
<th>S</th>
<th>Si</th>
<th>Cr</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.05–0.15</td>
<td>0.30–0.60</td>
<td>0.025 max.</td>
<td>0.50</td>
<td>1.90–2.60</td>
<td>0.87–1.13</td>
</tr>
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</table>

Table 2
Chemical composition of Inconel/Incoloy® 800 (wt.%) [2].

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
<th>S</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>Fe</th>
<th>Cu</th>
<th>Al</th>
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<tbody>
<tr>
<td></td>
<td>0.08</td>
<td>1.2</td>
<td>0.015</td>
<td>0.5</td>
<td>21</td>
<td>35</td>
<td>Balance</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Fig. 1. Schematic location of the failed tube in the boiler unit (left) and condition of the HTRH outlet header compartment consisting of stub tubes (SA213-T22) and HTRH Inconel/Incoloy® 800 tubes (right).
3. Microscopic examination

The microscopic examination on the failure region (heat affected zone) of the as-received stub tube showed numerous black nodules (Fig. 5) that were indicating that graphitization has occurred. In carbon steels and carbon–molybdenum alloys,
the iron carbide is unstable relative to decomposition into ferrite and graphite. Iron carbides can undergo two transformations at elevated temperatures as follows [3]:

(i) change in shape from a blade to sphere,
(ii) change from iron carbide to ferrite and graphite.

Since the failed tube had high metal temperature, chromium and molybdenum constituents of the SA213-T22 stub tube failed to prevent disassociation of iron carbides into iron and carbon (depletion of iron carbides in pearlite colonies), resulting in graphitization. The heat affected zone in a welding area is rapidly cooled or quenched structure [3]. The structure would graphitize more quickly than normal ferrite and pearlite. Thus, it is not unusual for heat affected zones to contain graphite. Decarburization is also seen in Fig. 5, but the pearlite colonies are still visible. The graphitization and decarburization would weaken the strength of the material and eventually lead to the tube rupture. This finding confirmed that the failed stub tube had operated at much higher metal temperature above the design operating temperature (540 °C).

4. Estimation of rupture times

The rupture time estimations for both SA213-T22 and Inconel/Incoloy® 800 tubes were carried out by utilizing diagrams of Larson–Miller parameter with stress variation to rupture of SA213-T22 [4] and Inconel/Incoloy® 800 (API 530) [5]. The minimum curves for Larson–Miller parameters versus the stresses to rupture in [4,5] were used for performing conservative estimations. The estimated hoop stress developed in the tube may be determined as

\[ \sigma_h = \frac{p (r + \frac{t}{2})}{t} \]  

where \( p \) is operational internal pressure; \( r \) and \( t \) are inner radius and wall thickness of the tube, respectively. In the Larson–Miller method, time and temperature for SA213-T22 steel are related by the following equation [4]:

\[ P = \left(\frac{9}{5} T + 492\right)(C_1 + \log t) \]  

where \( P \) is the Larson–Miller parameter; \( T \) is the temperature in °C; \( t \) is the rupture time in hours; \( C_1 \) is a constant equal to 20.

Time and temperature for Inconel/Incoloy® 800 material are related by the following equation [5]:

\[ P = (T + 273)(C_2 + \log t) \]  

where \( C_2 \) is a constant equal to 15.

It is found that the Larson–Miller parameters for internal steam pressure of 2.75 MPa or hoop stress of 17.01 MPa are 41,400 for SA213-T22 tube [4] and 21,600 for Inconel/Incoloy® 800 tube [5]. The rupture time estimations are presented in Table 3. It can be seen from Table 3, T22 tube will experience an earlier rupture compared to Inconel/Incoloy® 800 tube if they are subjected to the same operating pressure with the same metal temperature. In addition, even the operating metal temperature of T22 tube is much lower than that of Inconel/Incoloy® 800 tube, the T22 tube would first experience a rupture. It can be presumed that, if the service time of the tubes until the last outage is around 146,925 h and the time to rupture after the last outage was reported around 5050 h, an estimation of the temperature could be made from the calculated creep data of Table 3. The T22 tube is not expected to fail if the operating temperature is less than 630 °C. Therefore, it is believed that
the operating temperature had gone extremely beyond 700 °C, and the rupture of the T22 tube would be soon expected. However, the Inconel/Incoloy® 800 tube is able to withstand the higher operating temperature.

5. Discussion

In the last 1 year prior to the failure or since all the thermal plants of Kapar Power Station Malaysia have been forced to change their mode of operation from constant load to cyclic load, it was noticed that some of boiler components that rarely experience failure by fatigue in the past have begun to fail. It can be seen from Fig. 2 that the operational pressure in the high temperature reheater (HTRH) tubes are fluctuating. The thermal fatigue also contributed to worsen the problem, leading to a premature failure. Further, it is also confirmed that the failure would definitely occur at the inferior material of SA213-T22 stub tube. Meanwhile, the superior Inconel/Incoloy® 800 tube is categorized in the class of high-grade austenitic steel which could withstand high temperature operation. The difference of thermal expansion of the materials allows large temperature-induced stresses at the weld interface. Based on the evidences obtained during on-site observations, the most likely root cause resulting in the red hot HTRH tube (yellowish colour of the outer surface tube) and failure at the outlet header stub tube is due to steam starvation as a result of restriction in steam flow by blockage inside the HTRH Inconel/Incoloy® 800 tube. The impaired steam flow would cause the increasing tube metal temperature which results in overheating.

Flushing with the fire hydrant water into the HTRH tube during the outage has to be properly carried out to remove a lump of paper materials, metal debris and effluent materials in the tube-lines. Those unexpected materials could be deposited over period of time and they may travel elsewhere in tube-lines. Infra red camera systems can be imposed to continuously monitor vulnerable spots for growth of hot spots. Appropriate preventive maintenances should be considerably taken prior to arising of a more serious problem.

6. Conclusions

The findings revealed that the failed stub tube had operated at higher metal temperature above the design operating temperature. Steam flow starvation in HTRH Inconel/Incoloy® 800 tube (the superior tube) was identified to have caused the significant increase of the metal temperature. It consequently affected and caused overheating of the adjacent T22 stub tube (the inferior tube) which was followed by rupture. The rupture time estimations for different metal temperatures indicated that the inferior tube of SA213-T22 would first experience a rupture compared to the superior tube of Inconel/Incoloy® 800. The graphitization and decarburization in the metal structure also confirmed that the failed stub tube had operated at much higher metal temperature above the design operating temperature.

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References


