Properties of ERW Boiler Tube for Large-sized Generator

Abstract:

The ERW (electro-resistance-welded) tube has been widely adopted for boilers for a larger-sized power generator and its resultant valuation is placed high, and further, there is an increasing demand for applying it to the boilers because of its superior quality. In 1968, Nippon Steel Corporation started manufacturing the ERW boiler tube, and the amount manufactured so far has reached about six hundred thousands ton, which have been shipped inside and outside the country. Various manufacturing methods for the ERW boiler tube have been developed, and it has been attained to obtain superior quality characteristics. The results of a long term investigation on the aged deterioration of material, which was practically applied to the boiler for a large-sized generator, have proved its good quality including the corrosion resistance.

1. Introduction

Electric power demand is now increasing due to the development of the overall industry and the diversification of lifestyles. This trend is not limited to Japan, but rather is worldwide. Especially in countries other than Europe and the USA, potential demand is very high. From the viewpoint of supply, it is anticipated that thermal power generation will be as important as atomic power generation.

The problems that face these power-generation systems are high efficiency and economic operations from the viewpoint of conserving resources and energy. In the area of thermal power generation, the following items are under investigation:

- Large capacity;
- High temperature and high pressure;
- Coal burning;

Composite generation;
- Fluidized bed combustion, etc.

This trend leads to stricter boiler conditions and requires high quality and the use of economical materials.

In 1968, Nippon Steel started producing boiler tubes, the principal components of thermal power-generation boilers, by using high-frequency electric resistance welding (ERW). At the beginning, Nippon Steel started with carbon steel boiler tubes of the STB340 class (ASME SA178Gr.A), later expanding to STB410-class (ASME SA178Gr.C) tubes. In 1976, Nippon Steel succeeded in developing a low-alloy boiler tube of the STBA22 (1%Cr-0.5%Mo) class (ASME SA213Gr.T12). In 1980, the high-tension carbon steel boiler tube of the STB510^1 (ASME SA178Gr.D) was developed and began to be produced. Production of carbon steel and low-alloy boiler tubes now totals nearly 600,000 tons. They are so highly evaluated in the market that these days they are adopted by Japanese power-generating companies, as well as in business power station boilers overseas.

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^2 Kimita Works
The authors present the features of the production method of the ERW boiler tube at Nippon Steel, its properties, and aging due to long-term use.

2. Manufacturing Technologies of the ERW Boiler Tube

Fig. 1 shows the ERW boiler tube manufacturing processes and the key technologies used to manufacture the high-quality ERW boiler tube. The individual processes use peculiar technologies that have been developed over many years.

2.1 High-purity steel manufacturing technology

In recent years, highly purified steel manufacturing technology has shown significant progress, and its effects are remarkable. Amounts of steel impurities such as phosphor, sulfur, and oxygen have widely decreased, while the on-target ratio of the chemical composition has been increased. Phosphor, sulfur, and oxygen remain in steel in the form of segregation and non-metallic inclusions, and deteriorate properties such as strength, formability, weldability, toughness, and corrosion resistance substantially. To decrease them, long-term innovations in the manufacturing processes have developed the optimum refining process (ORP) to desulfurize prior to the main refining process in the LD oxygen bottom-blowing furnace (LD-OB), and secondary refining processes (KIP: Kimitusu Injection Process, RH: Rheinstahl Hutterwerke & Heraus) to desulfurize and deoxidize to produce high-purity steel.

2.2 High-quality ERW forming and welding technology

The key technologies in the ERW boiler-tube manufacturing process are forming and welding technologies. With respect to the former, optimization of the forming distribution and hole shape among the individual stands, and the development of cross-roll edge-forming (CRE) enables stable forming. This results in a more accurate thickness compared with the cold-rolled seamless pipe (SML COLD), as shown in Fig. 2.

Because the basic quality of the ERW boiler tube depends on welding, various developments have aimed at improving the welding technology. Firstly, the automatic weld control system is a typical example. In order to maintain the ERW welding temperature, the weld input heat is controlled based on continuous measurement of the tube wall thickness and welding speed. This results in a decrease in temperature variation, and contributes to stable quality.

Secondly, sealed welding technology is applied to alloy steel. If the steel containing Cr is welded in an air atmosphere, chromium oxide, which has a high melting point, will remain in the welded portion and cause defective welding, as Cr is more likely to be oxidized than Fe. The sealed welding technology is one of the measures that can prevent this defect. This technology decreases oxygen content to less than 30 ppm by means of inert gas, and suppresses the generation of oxidized chromium. Fig. 3 shows the sealing equipment. The sound-welded portion can be obtained by decreasing O₂ partial pressure in the welding atmosphere using N₂, Ar, He, etc.

2.3 Full-body normalizing by means of non-oxidizing and brightening heat treatment

Generally, in ERW welding, the ERW welded portion is harder than the base metal due to heating and cooling during welding. Structural homogenization is carried out by normalizing the whole piece of a tube in the non-oxidizing and brightening heat-treatment furnace, while maintaining the tube surface. Photo 1 shows the microstructure of the ERW welded portion, while Fig. 4 shows the hardness distribution of the ERW welded portion. By normalizing, the ERW welded portion obtains the same ferrite-pearlite structure as the base metal, and sufficient homo-
2.4 Highly accurate nondestructive inspection (NDI) technology

Due to the above material manufacturing technologies and ERW forming and welding technologies, a stable high-quality ERW boiler tube can be manufactured. From the view-point of quality assurance, however, a necessary and sufficient NDI is significant. Table 1 shows the outline of the NDI equipment. With respect to the ERW boiler tube, all of the above NDI are carried out. In the on-line testing of the welded portion and its surrounding area, and the outer surface of the tube is tested by means of angle-beam and surface-wave ultrasonic testing. In off-line testing, the entire tube is tested via angle-beam ultrasonic testing, and surface defects are tested via Eddy current testing (ECT). These NDI units are all fully automatic. Sensitivity adjustment, testing, alarm, marking, recording of test results, etc., are carried out automatically when a defect is detected.

3. Properties of the ERW Boiler Tube

The properties of the carbon steel tube, JIS G 3461 STB410 (ASME SA178 Gr.C), and the alloy tube, JIS G 3462 STBA22, (1%Cr-0.5%Mo) (ASME SA213Gr.T12) will be presented as typical examples of the ERW boiler tube.

3.1 Tensile properties at elevated temperatures

One of the most important properties required for the boiler tube is its tensile property at elevated temperatures. Figs. 5 and 6 show the tensile strength test results for the base metals, STB410 and STBA22. The samples are taken by cutting the tube longitudinally. The tensile strength test is carried out in the form of an arch. The base-metal sample and a sample that includes a welded portion are compared. The results satisfy the "Technical Standard for Thermal-Power Generation Equipment" (Thermal-Power Generation Standard of the Ministry of International Trade and Industry) and reveal good properties in general. The above comparison shows that there is no difference in strength, and that the welded portion has sufficient strength.

Figs. 7 and 8 show the creep rupture properties. The 100,000-hour rupture stress satisfies the allowable stress determined by MITI, and is equivalent to or more than the seamless pipe. As shown in Fig. 9, an internal pressure creep test is conducted to investigate the properties of an internally pressured tube containing an ERW welded portion. Most rupturing took place in the base metal, and the test shows sufficient strength in the base metal.

Table 1: Outline of a nondestructive inspection unit

<table>
<thead>
<tr>
<th>Equipment name</th>
<th>Probe X Units</th>
<th>Inspection area</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill-line, Angle beam UST</td>
<td>6×1</td>
<td>Welded portion</td>
<td>An automatic marking unit is included. The frequency is 2.25 MHz to 5 MHz.</td>
</tr>
<tr>
<td>Mill-line, Surface wave UST</td>
<td>2×1</td>
<td>Surface flaws around the welded portion</td>
<td></td>
</tr>
<tr>
<td>Inspection-line, Angle beam UST</td>
<td>10×1</td>
<td>Welded portion and base metal</td>
<td>An automatic marking unit and an alarm rejection unit are included. The frequency is 2.25 MHz to 5 MHz.</td>
</tr>
<tr>
<td>Inspection-line, ECT</td>
<td>1</td>
<td></td>
<td>An automatic marking unit and an alarm rejection unit are included. The frequency is 0.5 KHz to 16 KHz.</td>
</tr>
</tbody>
</table>
3.2 Formability

To construct a boiler, various kinds of forming technologies are applied to the boiler tube. Normal evaluation methods include flattening, flaring, crushing, and flanging tests. Because these tests are conducted on the form of the tube, the soundness of the ERW welded portion can be evaluated as well. It is essential that no rupturing occur at a certain degree of forming. Photo 2 shows the typical results of these tests and all the results indicate good formability. It is remarkable that there are no cracks in the ERW welded portion during the contact flattening test conducted after the flattening test.

Photo 3 shows the results of the bending test. Cold, hot, and contact bending formability tests were conducted with the ERW welded portion outside. In no test did cracks occur including the ERW welded portion. Results show that variations in the thickness, the outer diameter, the structure, and the hardness are small, and that the tube has excellent formability.

3.3 Weldabilities of joint

Photos 4 and 5 show the tensile and bending test results of the joint of the STB410. The joint was welded by TIG welding at the primary layer and by submerged-arc welding at the secondary layer and higher. For the TIG welding and submerged-arc welding, TGS-50 (2.4) and LB-26 (2.6) were used, respectively, without preheating. Annealing to eliminate the welded stress after welding (PWHT) was carried out by AC at 625±25°C for half an hour. The material as welded was also tested. In all the tensile strength tests made for a cut sample including an ERW welded
portion in one side, ruptures occurred in the base metal, where there is no ERW welded portion in the material as welded or the PWHT material. The tensile strength was 519 N/mm² with the material as welded, and 500 N/mm² with the PWHT material respectively. They are stronger than the material tube, which showed a strength of 470 N/mm². During the bending test no cracks occurred.

Photo 6 shows the macrostructure of the connection weld portion. The left side of the joint is the ERW welded portion. In the HAZ structure, neighborhood of the bond, the material as welded and the PWHT material have an acicular ferrite-pearlite structure, i.e. quench structure, while the base metal has a ferrite-pearlite structure. However, no abnormalities were found. No differences are recognized between the ERW welded portion and the nonwelded portion.

3.4 Corrosion resistance

Fig. 10 shows the investigation results of the weld-groove corrosion which is a kind of selective corrosion, of the ERW welded portion. A groove corrosion test was carried out under the conditions shown in Table 2. The effects of heat treatment were investigated by varying the sulfur content of steel. Although groove corrosion in the ERW decreases as the sulfur content decreases, groove corrosion is much less for the heat-treated tube (normalizing) after welding. For comparison, data is given on a continuous butt-welded tube in which groove corrosion is not thought to occur in actual conditions (drink water). Corrosion resistance equivalent to that of the continuous butt-welded tube can be obtained by decreasing the sulfur content and heat treating after welding. Groove corrosion is caused by sulfur in the MnS in steel, which is concentrated during cooling after welding and dissolves anodically into iron without MnS or concentrated S. As mentioned above, decreasing the sulfur content and heat treating are effective means of preventing corrosion.

Photos 7 and 8 show the corrosion test results of a tube that had been used in an actual boiler for three years and had been subject to hydrochloric acid corrosion tests and high-temperature steam corrosion tests. In both cases, no groove corrosion was found, and the tube remained sound.

3.5 Aging investigation in actual boilers
Periodically, samples of the ERW boiler tube are taken from actual large-scale power-generating boilers and aging is investigated\(^\text{11}\). Two examples are presented below.

### 3.5.1 Target boiler and investigation tube

Table 3 shows the main specifications of the investigated boilers and the history of the investigation tubes.

STB410 was used for the boiler tube in the No. 4 boiler (375 MW) at Tobata Cooperative Thermal Power Co., Inc. for 14 years, and STBA22 was used for the low-temperature heating tube in the No. 4 boiler (350 MW) at Kimitsu Cooperative Thermal Power Co., Inc., for 13 years. They are almost the same in structure. Fig. 11 shows their structures and sampling locations.

#### 3.5.2 Surface conditions

Photos 9 and 10 show the inner and outer surfaces of the sample tube and of a tube descaled by pickling. The outer surface of the STB410 boiler vaporizing tube is covered by white gray or dark deposits. Although the surface was roughened by pickling, it remained sound. On the other hand, the inner surface of tube is covered by a thin black film, and after pickling, it retains the same smooth surface it had when the boiler was manufactured. Neither local corrosion nor groove corrosion around the ERW welded portion can be observed on either surface.

The conditions of the STBA22 low-temperature superheater tube are similar to the STB410 boiler evaporated wall tube. The outer surface of the tube on the flame side is dark brown or brown, and is partially covered by white deposits. A thin black film sticks to the inner surface. After pickling, some spots can be seen on the outer surface, although the inner surface remains very smooth. Neither local corrosion nor groove corrosion around the ERW welded portion can be observed on either surface.

#### 3.5.3 Thickness of scales and deposits, and wear

Photo 11 shows the scales and deposits on the inner and outer surfaces of the section of the tube. Scales on the outer furnace consist primarily of Fe\(_2\)O\(_3\), and V, S, Na, K, etc., which apparently come from combustion gases, are detected on the deposits piled on the scales. The scales on the inner surface consist primarily of Fe\(_3\)O\(_4\).

Figs. 12 and 13 show amounts of scales and deposits. They basically have a tendency to increase (however, they are removed periodically). Figs. 14 and 15 show that there is very little wear, i.e., several \(\mu\)m per year.

#### 3.5.4 Microstructure

Photo 12 shows the microstructure as viewed through an

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**Fig. 10** Relationship between degree of groove corrosion and sulfur content in steel (Three-month immersion test with 3%NaCl conducted by the Nagoya Research and Development Laboratory)

**Table 2** Corrosion test conditions (NSC, Nagoya R&D Lab.)

<table>
<thead>
<tr>
<th>Size</th>
<th>40 mm x 50 mm x 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface conditions</td>
<td>#150 ground, corroded at the inner surface, submerged at the outside and surroundings</td>
</tr>
<tr>
<td>Solution</td>
<td>NaCl 3.0 wt%</td>
</tr>
<tr>
<td>Temperature</td>
<td>40°C</td>
</tr>
<tr>
<td>Gas</td>
<td>Air is always blown in (Oversaturated)</td>
</tr>
<tr>
<td>Flow speed</td>
<td>0.3 m/min</td>
</tr>
<tr>
<td>Immersion time</td>
<td>Three months</td>
</tr>
</tbody>
</table>
Table 3  Main specifications of the boilers and investigated tubes

<table>
<thead>
<tr>
<th>Item</th>
<th>No. 4 boiler, Tobata Co-Operative Thermal Power Co., Inc.</th>
<th>No. 4 boiler, Kainuzu Co-Operative Thermal Power Co., Inc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generating Capacity (MW)</td>
<td>375</td>
<td>350</td>
</tr>
<tr>
<td>Maximum steam flow (t/h)</td>
<td>1,180</td>
<td>1,130</td>
</tr>
<tr>
<td>Maximum working pressure (kg/cm²)</td>
<td>197</td>
<td>197</td>
</tr>
<tr>
<td>Steam temperature (°C)</td>
<td>569</td>
<td>569</td>
</tr>
<tr>
<td>Fuel</td>
<td>Mixed firing of blast furnace gas, coke oven gas, and heavy oil</td>
<td></td>
</tr>
<tr>
<td>Specification</td>
<td>JISG3461 STB410</td>
<td>JISG3462 STBA22</td>
</tr>
<tr>
<td>Nominal diameter (mm)</td>
<td>45 X 5.0</td>
<td>54 x 5.5</td>
</tr>
<tr>
<td>Sampled location</td>
<td>Evaporated wall tube</td>
<td>Low-temperature superheater tube</td>
</tr>
<tr>
<td>Applied conditions (Set value)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure (kg/cm²)</td>
<td>188</td>
<td>197</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>400</td>
<td>460</td>
</tr>
<tr>
<td>Operation starting date</td>
<td>May 1977</td>
<td>Dec. 1975</td>
</tr>
<tr>
<td>Sampling times</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Total number of operating hours</td>
<td>(Approx. 14 years)</td>
<td>(Approx. 13 years)</td>
</tr>
<tr>
<td>until the latest sampling (h)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Photo 9  Appearance of evaporated wall tube STB410 (Used for 14 years)

Photo 10  Appearance of low-temperature superheater STBA22 (Used for 13 years)

Photo 11  Scale and deposit conditions at the cross section of the tube

3.5.5  High-temperature tensile properties

Figs. 16 and 17 show high-temperature longitudinal tension test results. A comparison between the welded-portion sample, including the ERW welded portion at the center of the test piece, and the base-metal sample revealed no difference among these samples and the new tube in terms of strength and elongation.

3.5.6  Creep rupture properties

Figs. 18 and 19 show creep rupture results. The creep rupture test on the ERW welded portion and the base-metal portion was conducted in the longitudinal and circumferential directions. Comparison with the new tube revealed that no aging was recognized for any of the test pieces. The stress calculated based on the normal pressure applied to the tube is 7 to 8 kg/mm², and reaches 15% to 20% of the tensile strength at the temperature during use. Actual wear is considered to be very small.
Fig. 12  Transition of scale deposit amount (Evaporated wall tube)

Fig. 13  Transition of scale deposit amount (Low-temperature secondary superheater tube)

Fig. 14  Transition of tube wall thickness (Evaporated wall tube)

Fig. 15  Transition of tube wall thickness (Low-temperature secondary superheater tube)

Photo 12  Microstructure

Photo 13  Structure as observed through a transmission electronic microscope
Fig. 16 High-temperature tensile properties (Evaporated wall tube: STB410)

Fig. 17 High-temperature tensile properties (Low-temperature secondary superheater: STBA22)

4. Conclusion

The authors described the features of the manufacturing method and the properties of the ERW boiler tube used in large-scale power-generation plants. For formability, high-temperature properties, and corrosion resistance, it shows good properties, including the ERW welded portion. The aging evaluation of the tube used in actual boilers proves the good quality of the ERW boiler tube, including its corrosion resistance.

With the progress of manufacturing technology of seam weld-
ed pipes, large amounts of electric-resistance welded tubes have been put into use for large-scale boilers for power generation in which seamless tube are primarily used. However, the above results prove that the ERW boiler tube sufficiently meets the strict requirements for the ERW boiler tube. This manufacturing technology is based on long-term technical developments and their actual performance supporting them.

The authors would like to thank those concerned, both within and outside of Nippon Steel, for their cooperation.
References
4) Jyono, Shiko, Nogata : The Thermal and Nuclear Power. 27 (5), 25 (1976)
5) Narahara, Kasakari, Fukuda, Nogata : The Thermal and Nuclear Power. 27 (8), 31 (1976)
7) Kano, Yoshizawa, Sumimoto : The Thermal and Nuclear Power. 35 (6), 49 (1984)
8) Sumimoto, Masaoka, Yamamoto : The Thermal and Nuclear Power. 43 (5), 69 (1992)