Sandvik Sanicro 25 is an austenitic alloy with excellent high-temperature strength and corrosion resistance based on an economical composition.

R. Rautio, S. Bruce
Sandvik Materials Technology
Sandviken, Sweden

The power generation industry worldwide has identified a need for the development of coal-fired boilers operating at much higher efficiencies than the current generation of supercritical plants. This increased efficiency depends on ultrasupercritical steam conditions that require new materials for critical components. Sandvik has developed an austenitic alloy, Sanicro 25, with excellent high temperature strength and corrosion resistance based on an economical compositional balance of alloys. The alloy has been developed for service at steam conditions of 700°C (1300°F)/300 bar (4500 psi). This article provides an introduction to the alloy, its development status, and its properties.

Alloy concept
A conceptual study resulted in 13 trial casts of material with varying compositions that were considered to have potential to meet the targets of 100,000 hour creep rupture strength of 100 MPa (14.5 ksi) at 700°C (1300°F), together with fireside corrosion resistance better than that of NF709. A small melt was produced for each of the 13 development compositions, and one melt for reference heat 14, which was based on grade NF709.

A suitable forging temperature had to be predicted for all the experimental melts. This was done by hot ductility testing in a Gleeble machine. Prior to hot ductility testing, all of the specimens were heat treated for 30 minutes at 1100°C (2000°F), followed by water cooling. From the test results, the optimum hot forging temperatures were predicted.

All ingots were processed by forging bar to a diameter of 87 mm, followed by extrusion to a diameter of 29 mm in the laboratory pilot scale press. After extrusion, the bars were heat treated. Six specimens from all charges were exposed to three different temperatures: 1100°C (2000°F), 1150°C (2100°F), and 1200°C (2200°F) for two different time durations. Bars were then evaluated in terms of grain size and amount of precipitates. Based on this evaluation, it was decided to heat treat the experimental grades at 1150 to 1200°C (2100 to 2200°F) followed by water cooling.

Following several screening tests, heat 6 was selected because of its superior creep strength and good mechanical properties. The table shows its chemical composition.

Heat 15
As part of the evaluation of the selected alloy, manufacture of further test material in tubular form was required. The tube size selected for testing had a diameter of 41.4 mm, with 8 mm average wall thickness in cold pilgered and annealed finish. A new melt was produced, called heat 15, based on the chemical composition for heat 6, see table.

The selected alloy was successfully produced by extrusion to a tube diameter of 73.0 mm with

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### Chemical composition of heats 6 and 15, and Sanicro 25

<table>
<thead>
<tr>
<th>Alloy</th>
<th>C max</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>Ni</th>
<th>W</th>
<th>Co</th>
<th>Cu</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat 6</td>
<td>0.08</td>
<td>0.2</td>
<td>0.5</td>
<td>22.2</td>
<td>24.9</td>
<td>3.5</td>
<td>1.5</td>
<td>3.0</td>
<td>Nb=0.49 N=0.23</td>
</tr>
<tr>
<td>Heat 15</td>
<td>0.08</td>
<td>0.25</td>
<td>0.51</td>
<td>22.6</td>
<td>25.5</td>
<td>3.45</td>
<td>1.57</td>
<td>2.99</td>
<td>Nb=0.44 N=0.24</td>
</tr>
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<td>Sanicro 25</td>
<td>0.1</td>
<td>0.2</td>
<td>0.5</td>
<td>22.5</td>
<td>25</td>
<td>3.6</td>
<td>1.5</td>
<td>3.0</td>
<td>Nb=0.5 N=0.23</td>
</tr>
</tbody>
</table>
Fig. 1 — Creep-rupture strength at 700°C.

Fig. 2 — Low-cycle fatigue data showing the total strain range for several alloys.

To ensure a balanced composition, consideration has been given to the effects of high chromium and tungsten levels, which promote formation of sigma phase. For this reason, the nickel content has been increased to approximately 25.0 wt%, together with a relatively high amount of nitrogen. For similar reasons, the levels of molybdenum and silicon have been kept relatively low. Composition of Sanicro 25 is shown in the table.

**Creep strength testing**

The creep strength target is 100 MPa (14.5ksi), 700°C (1300°F), at 100,000 hours. With this target in mind, metallurgists designed the stresses for the creep tests at 650°C (1200°F) and 700°C (1300°F) to give estimated test duration time-to-fracture of 1000, 3000, 10,000, 30,000, and 70,000 hours. Stresses for testing at 750°C (1390°F) were designed for shorter durations than those for the lower two temperatures.

Ongoing creep-rupture tests with test durations above 25,000 hours indicated that the mechanical target 100 MPa (14.5 ksi), 700°C (1300°F) at 100,000 hours will be achieved for the bar material.

Test data also indicate that the mechanical target 100 MPa (14.5 ksi), 700°C (1300°F) at 100,000 hours could be achieved for tube material. However, more test time is needed to assure that the target will be achieved.

Based on the data from test times up to 5000 hours, creep rupture time for the tube is estimated to be between 70,000 and 100,000 hours for 100 MPa (14.5 ksi) at 700°C (1300°F). It should be noted that Sanicro 25 has longer creep rupture time than shown in the literature data for HR3C and NF709 at 700°C (1300°F), see Fig. 1.

**Fatigue test**

Powergen tested Sanicro 25 and two commercially materials, SAVE25, and NF709 for low cycle fatigue (LCF). All three materials were tested in the as-received condition. Sanicro 25 and SAVE25 were also tested in the aged condition, with Sanicro 25 aged at 700°C (1300°F) for 2000 hours, and SAVE25 aged at 700°C (1300°F) for 3000 hours.

All the materials gave essentially similar results in the LCF test, see Fig. 2. Tensile dwells had a significant effect on reducing endurance in both SAVE25 and Sanicro 25 compared with continuous cycling. However, when examined in terms of the plastic strain range during testing, the dwell and continuous cycling data fall on the trend line for each material. This would suggest that a five-minute dwell has little effect in terms of creep damage contribution, but merely modifies the stress-strain loop by increasing the plastic strain contribution via stress relaxation in the dwell.

**Microstructural examination**

Tubes from heat 15 and bar from heat 6 were characterized via microscopic examination. Samples in the as-delivered condition were aged for 1000 hours at 700°C (1300°F) and aged for 3000 hours.

**Fig. 1** Creep-rupture strength at 700°C.

**Fig. 2** Low-cycle fatigue data showing the total strain range for several alloys.

Wall thickness 11.0 mm. This was followed by cold pilgering to the final diameter of 41.4 mm and wall thickness 8 mm, followed by solution annealing.

Superheater tube with a diameter of 41.4 mm and wall thickness of 8 mm was successfully produced, with welding and bending operations on the tube showing good results.

Extruded bars with a length of 2.2 m (7 ft) were pickled and straightened. After straightening, they were cold drawn in three passes without intermediate heat treatments between the drawing passes. The final diameter for the bars was 16.6 mm. This resulted in a primary reduction of area.

**Alloy composition**

The requirements of the new austenitic grade for ultrasupercritical coal-fired boiler tubes include high creep and oxidation resistance, high microstructural stability, and good fabricability. Meeting these objectives required the application of a number of basic alloy design principles.

The main technique for reaching the very high elevated-temperature strength is precipitate strengthening through utilization of Nb(C,N), fine NbCrN, M23C6, and Cu-rich precipitates. High-temperature strength is also improved by the addition of tungsten.

To improve the hot corrosion resistance, chromium content is approximately 22.5 to 24.0 wt%, together with low molybdenum content.
hours at 700°C (1300°F), and were then examined via the scanning electron microscope (SEM). The samples aged for 1000 hours at 700°C (1300°F) were also examined via transmission electron microscope (TEM).

Results showed that samples in the as-delivered condition contained niobium-rich precipitates that were also enriched with chromium. The aged samples contained small needle-shaped M23C6 in both the grains and grain boundaries. Sigma-phase and Cr2N were not detected in the samples aged for 1000 hours and 3000 hours. The grain size for the tubes was 5.0 ASTM, and the grain size for the experimental bar was 5.5 ASTM.

**Hot corrosion**

Hot corrosion tests were carried out at 700°C (1300°F) for an exposure time of 3000 hours by Ansaldo Ricerche s.r.i. NF709 was chosen as a reference material because it is known as one of the best commercially available steels in this respect. Test specimens of both NF709 and Sanicro 25 were covered with ash and exposed to a gas flow during the test time.

The ash composition was 5% Na2SO4, 5% K2SO4, 30% Fe2O3, 30% Al2O3 , and 30% SiO2. Gas composition was 0.25% SO2, 3.5% O2, 15% CO2, and balance of N2.

The samples were covered by a fixed amount of ashes in an ethyl alcohol suspension. Ashes were renewed every 100 hours for the first 500 hours of testing, and then every 500 hours up to the end of the test at 3000 hours.

This methodology assures a better exchange between gas environment and metal surface, and consequently provides a better simulation of the material performance in service.

After exposure, corroded samples were subjected to a chemical descaling process to determine the mass change for each material as a function of test duration. Figure 3 shows results for the two materials. It is clear from the graph that Sanicro 25 has a much lower corrosion rate than NF709.

Also, corrosion morphology differs greatly from one material to the other. Sanicro 25 is characterized by localized corrosion with some deep pits, especially after longer exposure. NF709 shows a more uniform corrosion front with a great loss of thickness after 3000 hours of exposure.

**Tensile properties**

Tensile tests on Sanicro 25 from heat 15 have been performed at the temperature range from 20°C (70°F) to 800°C (1500°F) with two specimens tested at each temperature, Fig. 4.

Test data from ongoing mechanical testing of tube material indicate that the mechanical target 100 MPa (14.5ksi) at 700°C (1300°F) at 100,000 hours could be achieved. However, more test time is needed to be sure that the target will be achieved for tube material. However, the data available so far show that the creep rupture time of the tube material will be between 70,000 and 100,000 hours for 100 MPa (14.5ksi) at 700°C (1300°F). The tests also show that Sanicro 25 has notably longer creep rupture time compared to NF709 at 700°C (1300°F).

**Operational capabilities**

The operational capabilities of Sandvik Sanicro 25, together with new technology, mean that boiler temperatures can be increased significantly over traditional power stations. This allows an increase in operational efficiency of up to >50% (compared with today’s 35 to 45%). The ability to run at higher temperatures and pressures increases efficiency and as a result has a significant effect in reducing carbon dioxide emissions per kW of electricity produced.

*For more information:* Tom Kern, Sandvik Materials Technology, 982 Griffin Pond Road, Clarks Summit, PA 18411; tel: 800/755-8823, ext. 7639; tom.kern@sandvik.com; boiler.smt@sandvik.com; www.smt.sandvik.com/boiler.

This article is based on a paper titled *Sandvik Sanicro 25, A new material for ultr-supercritical coal fired boilers*. The paper has many more details than shown here, and is available on the Sandvik Materials Technology website, at www. www.smt.sandvik.com/boiler.