Materials

ORNL Facility Evaluates High Temperature Recuperator Materials

New Alloy Demonstrates Outstanding Creep and Corrosion Resistance at High Temperatures

Background

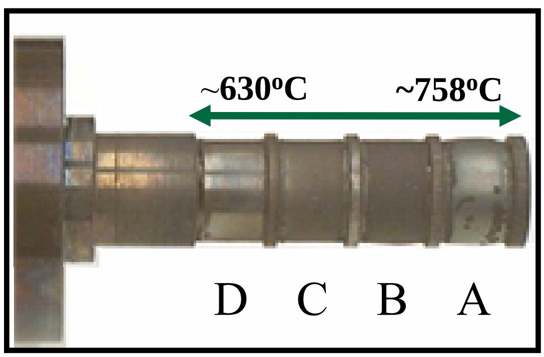
One of the most challenging performance targets for the next generation of microturbines requires fuel-to-electricity efficiency of 40%. Significant increases in microturbine efficiency can be achieved by increasing the engine-operating temperature, but this can only be realized through the use of advanced metallic alloys for high temperature recuperator material. Most modern microturbine recuperators are manufactured with 300-series stainless steels and are used at exhaust-gas temperatures below 600°C. At higher temperatures, these materials are susceptible to creep formation and oxidation, which lead to a reduction in the effectiveness and life of the recuperator.

ORNL Microturbine Recuperator Test Facility

As part of the U.S. DOE Advanced Microturbines Program, a test facility was established at ORNL to screen and evaluate candidate, next generation recuperator materials. Several alloys have been evaluated at the facility in collaboration with Capstone Turbine Corporation, Ingersoll Rand, and Solar Turbines. Haynes Alloy 120®, demonstrated excellent creep and corrosion resistance after 500 h exposure tests at temperatures as high as 760°C.

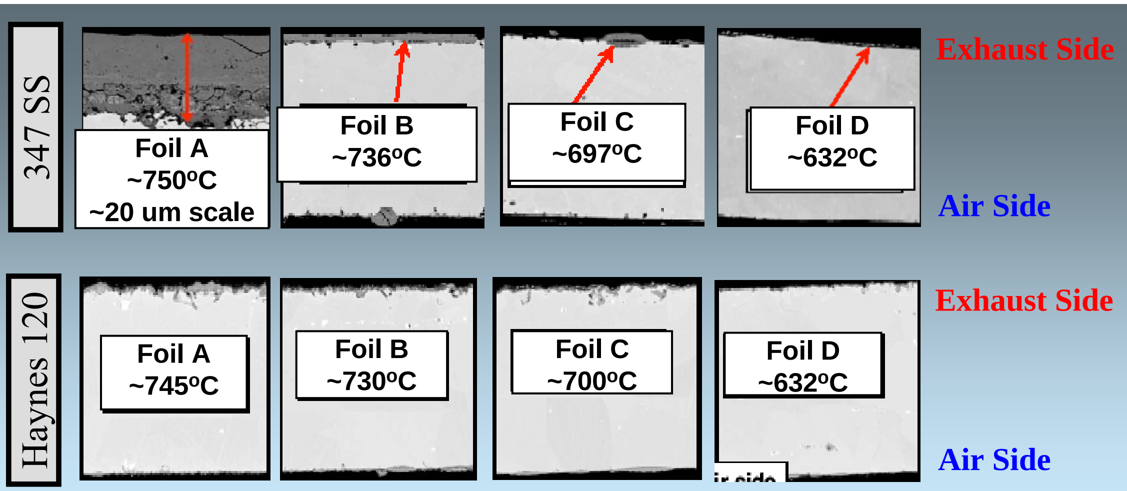
Technology

The ORNL facility uses a 60kW Capstone microturbine which is modified to achieve higher turbine exit temperatures. To simulate the pressure differential experienced by the recuperator during service, thin metallic foil test specimens are welded onto a sample holder and mechanically stressed by pressurizing the sample holder with air. The specialized configuration of the microturbine allows the screening of test specimens over a wide range of temperatures in one test. After exposure, the residual mechanical properties of the test specimens are determined through tensile testing and their microstructure and composition is characterized using analytical electron microscopy.



After exposure, foils are removed from the sample holder and evaluated for microstructural change and residual tensile strength.

The thickness of the oxide layer forming on the surface of 347 stainless steel (347 SS) foils was found to increase with temperature and become more than 20-µm thick after a 500-hr exposure at 760°C. The presence of water vapor in the microturbine exhaust gas stream leads to rapid growth of Cr_2O_3 followed by its evaporation as $CrO_2(OH)_2$. These two processes lead to an increased consumption rate of chromium in the metal compared to oxidation in dry air. Because the diffusion rate of chromium in the metal is not fast enough compared to the consumption rate, a chromium depleted region forms in the metal near the surface exposed to the exhaust gases. After an incubation period, nodules of iron oxide begin to form leading to accelerated attack. The 347 SS specimen also loses 50% of its tensile strength after the 500 h exposure at 760°C. In contrast, after a comparable exposure period the Haynes 120® alloy retains 85% of its ultimate strength and the corrosion products that form on the surface are much thinner. Haynes 120® alloy is one of the leading candidate alloys to manufacture the next generation of microturbine recuperators.



Corrosion of materials after a 500 h exposure test. 347 SS formed a 20 µm thick oxide scale on the exhaust side (top of image) while Haynes Alloy 120 demonstrates very thin oxide scales, even at the highest temperature of 750 ºC .

Benefits

The screening and evaluation of candidate recuperator materials in the actual operating environment of a next generation microturbine is a valuable capability provided by the ORNL Microturbine Recuperator Test Facility. Exposure tests can be carried out at temperatures as high as 850°C and at compression ratios of 15:1. Exposure tests, combined with subsequent mechanical and microstructural characterization of the materials examined provide information on the mechanisms responsible for their corrosion resistance (or lack thereof) and ways to modify them to improve their performance.

Future Work

In addition to Haynes 120® alloy, the behaviors of alloy 625, Haynes 214® and 230®, ORNL-modified stainless steels, and FeCrAlY are being investigated.

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