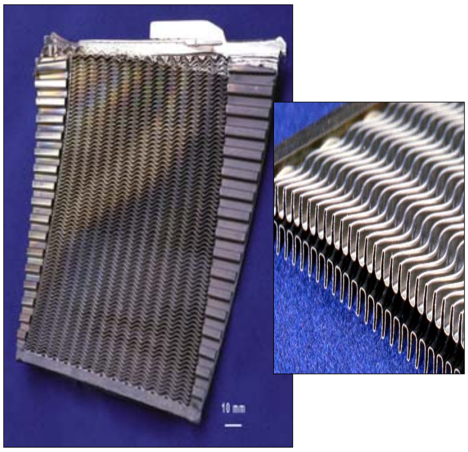
Long-Term Testing of Recuperator Alloys Provides Insight Into Oxidation Mechanisms

Recuperator Life Estimated Based on Cr-Depletion Rates

Background

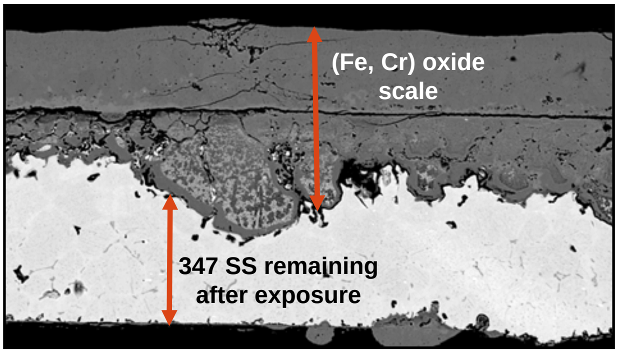
Higher temperature recuperator components are critical for improving the efficiency of microturbines to >40% and a primary focus area of the Department of Energy's Advanced Microturbine Program. Type 347 stainless steel (347SS) foil has traditionally been used for thin-walled recuperator components due to its creep and corrosion resistance at temperatures up to ~600°C. Improved microturbine efficiency, however, will require increasing the turbine inlet temperature (thereby increasing the exhaust gas/recupertor inlet temperature) to >600°C. Oak Ridge National Laboratory (ORNL) is leading an effort to develop and characterize alloys with improved high-temperature performance for higher efficiency recuperators.



Primary surface recuperator air cell made from corrugated type 347 stainless steel foil

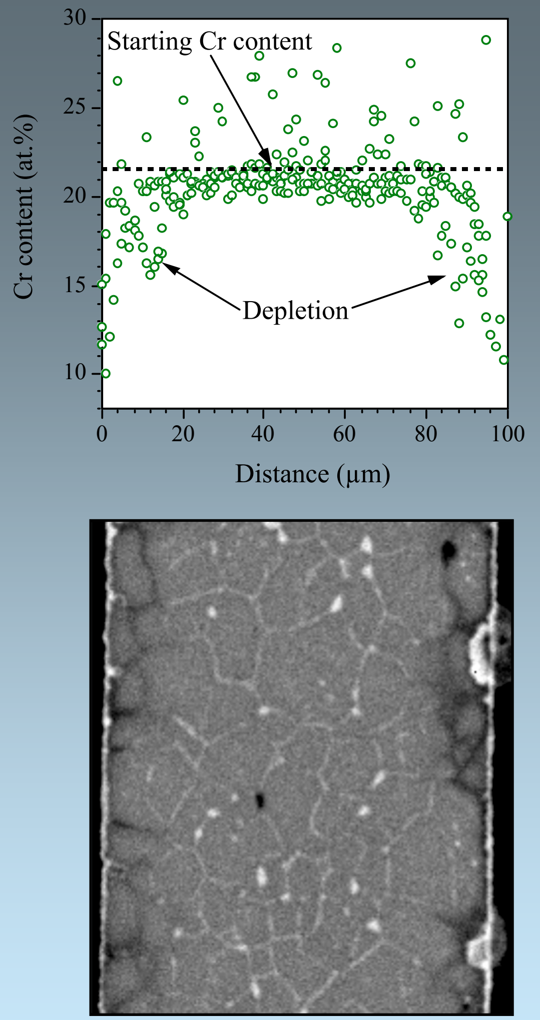
Technology

Recently, 10,000 h cyclic testing was completed on a series of commercial foil specimens; results from these tests are being used to better understand the detrimental effect of water vapor and the role of temperature on increasing the rate of corrosive attack. Air containing 10% water vapor and temperatures ranging from 650-800°C were used to simulate the microturbine exhaust-gas environment. Results at 650°C show that while 347SS showed accelerated attack and failure after exposure for <2000 h (rapid weight gain), the more durable alloys (120, 625, and 20/25/Nb) had much lower weight changes after exposure for 10,000 h. Mass change is a combination of oxygen uptake to form a surface oxide and mass loss due to the volatilization of chromium oxy-hydroxides. Specimen mass change is continuously monitored during corrosion testing and microstructural and compositional analyses are conducted on exposed foils at different time intervals.



Type 347 SS exposed in a microturbine at >650°C shows excessive surface corrosion. Alloys with improved corrosion resistance will be required for higher-temperature recuperators.

A series of laboratory exposures has shown chromium depletion to be one of the most important factors in predicting long-term alloy durability. Only a limited reservoir of chromium is contained in thin cross-section of the foil, and accelerated corrosive attack occurs when the chromium content drops below a critical level. Chromium depletion profiles across the cross-sectional thickness of the foils are being monitored as a function of time and will be used to predict alloy lifetimes at a given temperature. Elemental chromium maps are used along with the chromium profiles to evaluate additional changes in chromium distribution across the thickness of the foil. Chromium mapping shows regions of depletion, particularly along the grain precipitates in the center of the foil and at the surface oxide.



Typical chromium profile with corresponding chromium elemental map across foil cross-section showing chromium depletion at foil surfaces (Fe-20Cr-25Ni+Nb after 10,000h at 700°C in air + 10% H_2O).

Benefits

Conventional 347 SS recuperators cannot operate at temperatures >600°C without a significant loss in durability due to accelerated corrosive attack. The initial goal of the ORNL research was to identify higher-temperature alloys with improved corrosion resistance that could be used for this application at temperatures of 650-700°C. Long term laboratory testing has shown that several alloys, such as 120, 625, and 20/25/Nb (now being commercialized by Allegheny Ludlum), have demonstrated significantly higher temperature durability compared to 347 SS. Using these alloys will allow higher microturbine operating temperatures, with a commensurate increase in engine efficiency, while meeting the durability goals necessary for continuous operation to 40,000 h. Subsequent work will attempt to identify new, lower-cost compositions, which will assist in meeting cost reduction targets for microturbines.

Future Work

Laboratory testing of commercial and model alloys will continue in order to better understand the role of water vapor on the corrosion behavior of austenitic alloys. This information will assist in the development of better lifetime prediction capabilities and lower cost alloys for this application.

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