SAND2020-13305R

STEP Materials Development
Task 02.01.03
Supercritical Transformational Electric Power Generation (STEP)

Milestone Report

Effect of High Temperature CO_2 on Haynes 230 Alloy

Bonnie Antoun
Arthur Kariya

Sandia National Laboratories, Livermore, CA

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1. Introduction

The supercritical carbon dioxide (sCO_2) Brayton cycle is a promising candidate for future nuclear reactors due to its ability to improve power cycle energy conversion efficiency. The sCO_2 Brayton cycle can operate with an efficiency of 45-50% at operating temperatures of 550-700 C. One of the greatest hurdles currently faced by sCO_2 Brayton cycles is the extreme corrosivity of sCO_2. This affects the longevity of the power cycle and thus the levelized cost of electricity.

Past studies have shown that sCO_2 corrosion occurs through the formation of metal carbonates, oxide layers, and carburization [1], and alloys with Cr, Mo and Ni generally exhibit less corrosion [2]. While stainless steels may offer sufficient corrosion resistance at the lower range of temperatures seen by the sCO_2 Brayton cycles, more expensive alloys such as Inconel and Haynes are typically needed for the higher temperature regions. This study investigates the effects of corrosion on the Haynes 230 alloy, focusing on changes in the mechanical properties.

2. Experimental approach

The corrosive effects of high temperature CO_2 on Haynes 230 alloy was investigated by subjecting the alloy samples to CO_2 at 650 C for 500, 1000, and 1500 hours. For each period of exposure, the samples were tested for change in mechanical properties. Each exposure period had 3 samples each, for a total of 9 samples. Exposure was performed in a Lindberg-Blue 150 mm diameter tube furnace with a fused quartz tube. The furnace features three-zone heating over a span of 3 feet, with independent zone temperature control for temperature uniformity (Figure 1). The quartz tube was closed on each end with water-cooled stainless steel caps sealed with a gas-tight silicone seal. Each cap has a port for gas entry and exit; a completely CO_2 atmosphere was maintained with a constant flow of CO_2 from a gas cylinder at 150-200 mL/min. After inserting the samples, the furnace was purged with this flow rate for over 20 hours before heating to ensure that the tube is purged of all other gases. This flow rate also ensured that a slightly positive pressure is maintained inside the tube to prevent air ingress, and is continued through the entire CO_2 exposure.

Figure 1. Tube furnace used for high temperature CO_2 corrosion tests.

After CO_2 exposure, the tensile specimen samples were tested in tension at 750 C to failure. Additional tensile specimens were also tested that had no CO_2 exposure for comparison. The mechanical behavior was assessed as a function of CO_2 exposure times and correlated with measurements from the failed samples. The specimens had a nominal gage section diameter of 0.25 inches (6.35 mm). These mechanical tests were conducted on a 50 kip axial/torsional servohydraulic MTS test frame, shown in Figure 2. Tests were conducted in actuator displacement control at a rate of 0.001 inches per second. A high temperature extensometer was attached to measure strain accurately in the specimen gage section, with a starting gage length of about 0.75 inches (19 mm). In addition to the test frame load cell, a secondary load cell with 10 kip capacity was used for accurate load measurement. A three-zone furnace was used to provide uniform heating along the length of the samples during testing, shown in Figure 3. Two type K thermocouples were attached to each specimen above and below the gage section to measure temperature directly from the specimens.

One specimen of each CO_2 exposure condition was reserved for planned fatigue testing at 750 C. For the eight tensile tests, data was collected at 1000 Hz for the following signals: displacement, 50 kip load cell, 10 kip load cell, extensometer, top thermocouple, and bottom thermocouple. The 10 kip load cell and extensometer measurements were used to calculate engineering stress and strain shown in the results.

Figure 2. Elevated temperature tensile test setup on 50 kip Axial/Torsional test frame.

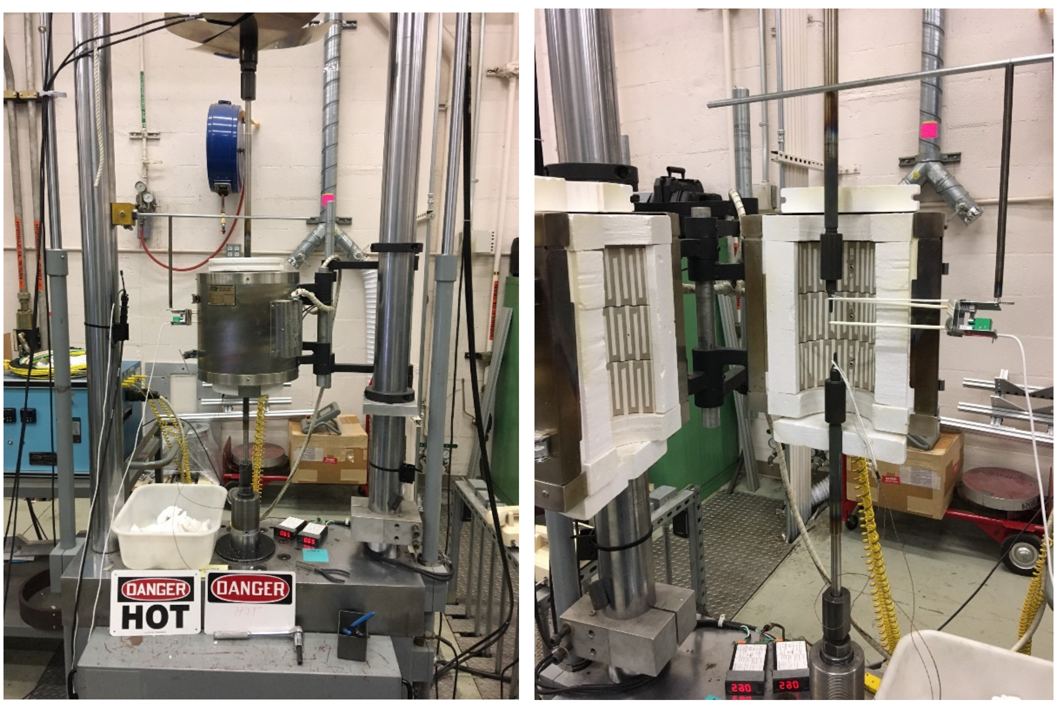

Figure 3. Three zone ATS furnace and controller (left) and specimen after failure (right).

3. **Results**

The results for all eight 750 C tensile tests are shown in Figure 4. No discernable difference was seen in the response with increased CO_2 exposure time. This material in its wrought form appears to be insensitive to CO_2 exposure at 650 C. These results will provide a baseline for comparison to diffusion bonded forms of this alloy. Additionally, the planned 750 C fatigue testing of the remaining specimens will determine if the alloy remains insensitive when subjected to repeated loadings.

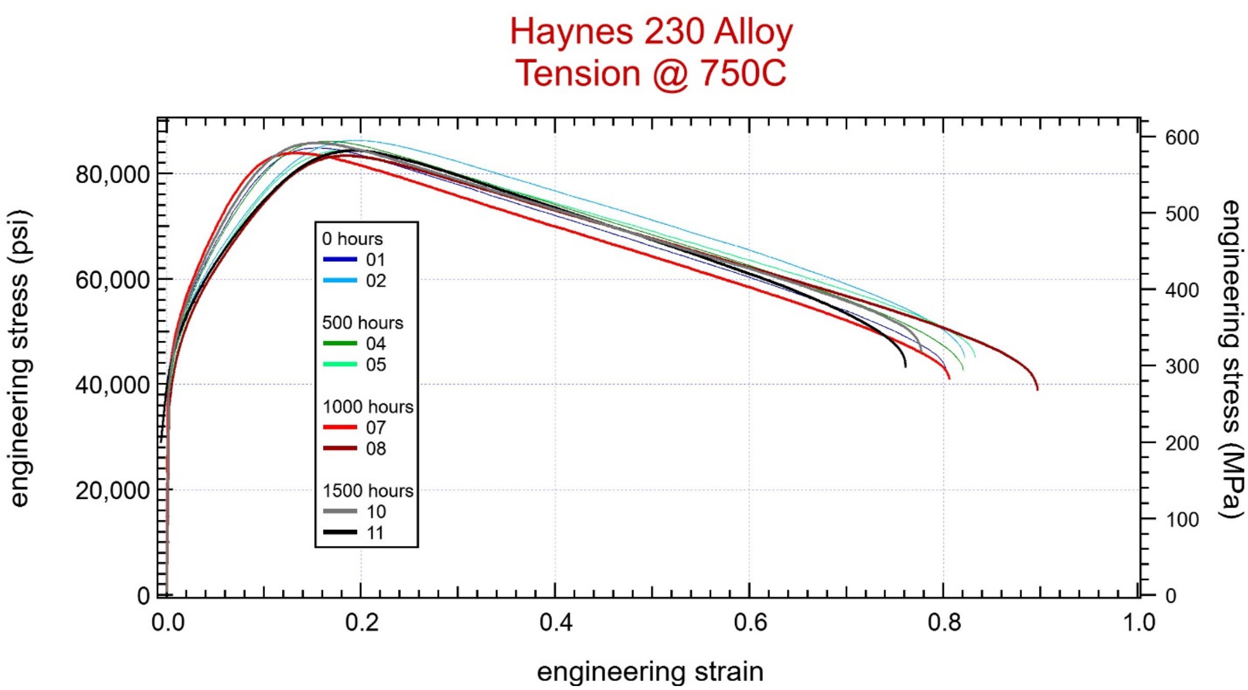

Figure 4. 750 C tensile behavior for all CO2 exposure times.

The corrosive effects of high temperature CO_2 on the Haynes 230 alloy is currently being analyzed with SEM/EDS, with scans of the flat section of the tensile test specimen (external surface), as well as of a cross-sectional scan of the specimen subjected to 1000 hours of CO_2. The cross-sectional scan will elucidate the level of corrosion penetration into the material, which will have a bearing on cases with thin material. The elemental analyses are expected to be completed by December 4, 2020.

REFERENCES

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2. Loriers, H., Leclercq, D. and Darras, R, “Corrosion Des Aciers Faiblement Allies Dans Le Gaz Carbonique Aux temperatures Moyennes” Journal of Nuclear Materials Vol. 24, pp. 144-159, 1968.