Oxidation of Yttrium Hydride Moderator for the Transformational Challenge Reactor

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INTRODUCTION

The US Department of Energy has launched the Transformational Challenge Reactor (TCR) program to build, qualify, and operate an additively manufactured microreactor core at Oak Ridge National Laboratory (ORNL) to demonstrate a more efficient, effective, and quicker approach to advanced nuclear energy [1]. Yttrium hydride (YH_x) has been selected as the moderator material for the TCR due to its excellent moderating ratio, relatively low weight, superior thermal stability, and exceptionally high number density of hydrogen. The use of YH_x moderator helps to minimize the amount of nuclear fuel and reduce the reactor core size. Hu *et al*. recently demonstrated the capability of producing dense, crack-free YH_x with a variety of H/Y atomic ratios [2][3]. Although air ingress into the core and failure of moderator sheath (Grade 316 austenitic stainless steel) is not deemed a credible accident scenario given the TCR core and reactor system design, understanding the oxidation behavior of YH_x is useful. In this way one may predict the moderator behavior under accident scenarios when it is exposed to air in support of advanced nuclear reactor systems that utilized this novel moderator. Work has begun at ORNL to understand the oxidation behavior of YH_x and is presently reported.

OXIDATION TESTING

Crack-free YH_x coupons (10 × 20 × 1 mm) with H/Y ratios of 1.0, 1.62. 1.77, 1.87, and 1.91 were fabricated via the hydriding process outlined by Hu *et al.* [3]. Thermogravimetric analysis (TGA) testing was conducted with a Cahn TGA microbalance. Samples were suspended in a furnace with an Rh-Pt Type B thermocouple wire, and mass change was monitored externally with LabView. Isothermal exposures were conducted in dry air for 4 h at 550°, 600°, and 650°C.

RESULTS

Specimen mass gain during 4 h of isothermal exposure at 650°C in flowing dry air is shown in Figure 1(a). Mass gain was observed to decrease with increasing hydrogen content. Mass gain is plotted against $t^{1/2}$ in Figure 1(b), such that

$$\Delta w/A = (k_p t)^{1/2}$$

where $\Delta w/A$ is the specimen mass gain in mg/cm^2, t is time in hours, and k_p is the parabolic rate constant in units of mg^2/cm^{4}h. When plotted in this manner, linear regimes indicate parabolic, or diffusion-controlled, kinetics. As can be seen in Fig. 1(b), YH_x exhibited two parabolic regimes, k_{p1} and k_{p2}, before transitioning to linear breakaway oxidation. The time intervals over which k_{p2} occurred were found to generally be significantly longer than the time intervals for k_{p1}. For the hydride coupons having higher hydrogen

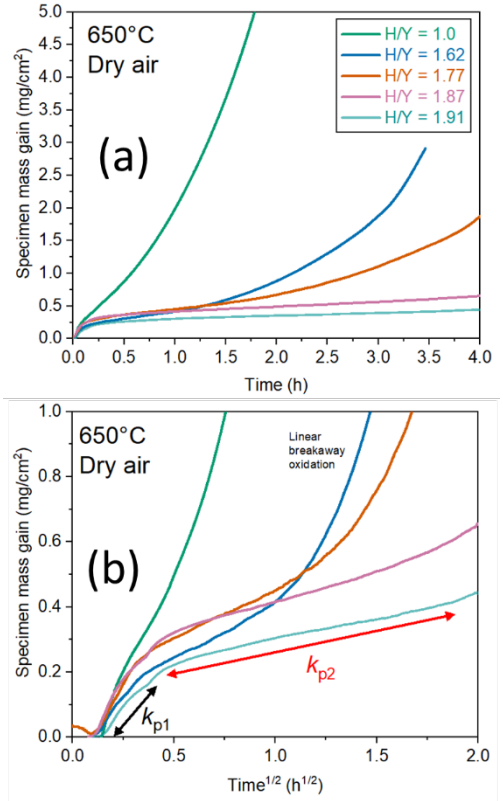

Fig. 1. (a) TGA mass gain during 4 h of 650°C exposure in flowing dry air. (b) Mass gain plotted against $t^{1/2}$.

concentrations ($YH_{1.87}$ and $YH_{1.91}$), breakaway oxidation did not occur within the 4 h exposure, although the small upward trend at the end of the testing indicates that the linear regime might have been beginning. Similar behavior was observed at 550°C and 600°C (not shown).

Both k_{p1} and k_{p2} obtained from 650°C oxidation are plotted against H/Y ratio in Fig. 2. An R^2 value of 0.644 was found for k_{p1}, indicating poor correlation, and 0.938 for k_{p2}, indicating good correlation. Similar relationships between parabolic rate constant and H/Y ratio were found at 550°C and 600°C. Specimen mass gain determined via initial and final masses were in good agreement with observed k_{p2} values—coupons with higher H/Y ratios possessed lower rate constants and gained less mass due to oxidation.

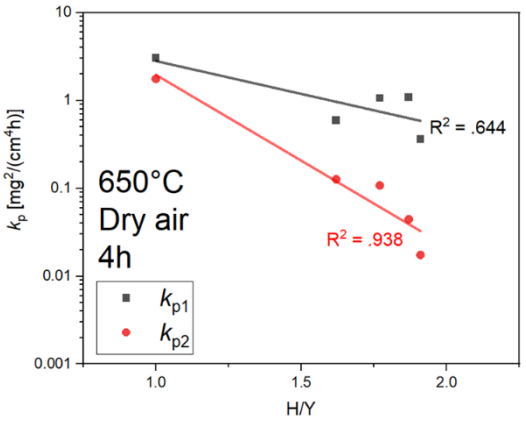

Fig. 2. Relationship between H/Y ratio and k_{p1} (black) and k_{p2} (red) at 650°C.

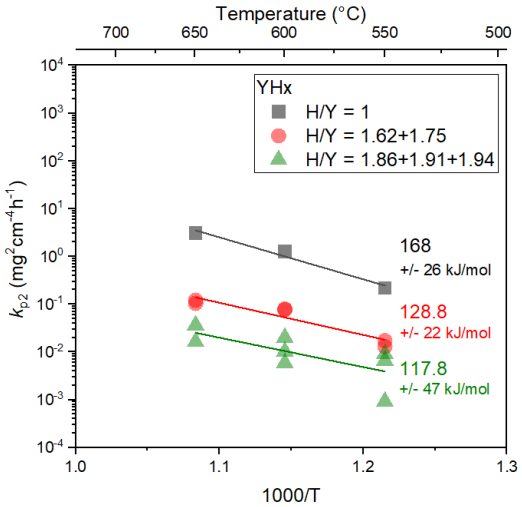

Fig. 3. Arrhenius plot of k_{p2} values categorized into H/Y = 1.0, 1.61–1.76, and 1.86–1.93.

Values of k_{p2} were found to generally fall within three H/Y groupings, H/Y = 1.0, H/Y = 1.61–1.76, and H/Y = 1.86–1.93. An Arrhenius plot where k_{p2} is plotted in these categories is shown in Fig. 3. Activation energies of 168, 128.8, and 117.8 kJ/mol were obtained for the three H/Y groupings, respectively.

SUMMARY

This report summarizes initial oxidation studies of YH_x for use as a moderator in the TCR. TGA was used to determine oxidation kinetics in the range of 550° to 650°C for YH_x coupons with H/Y ratios of 1.0 to 1.93. Experiments revealed parabolic behavior that transitioned to linear breakaway oxidation for samples having lower hydrogen content, with the parabolic behavior apparently consisting of two regimes. The second regime correlated well with H/Y content and total mass gain during exposure and thus is an appropriate metric to evaluate the impact that the H/Y ratio has on oxidation. Metallographic cross-sectioning characterization is ongoing and will be discussed in future reports. Oxidation exposures in environments more relevant to the TCR will be conducted in the future.

ACKNOWLEDGMENTS

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