$AddH_2$ – SP3: Hydrogen Flame Effects and Long-Term Aging of Additively Manufactured Ceramics in Hydrogen Combustion Atmosphere

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Overview

Hydrogen offers clean energy potential but poses severe material challenges. This project investigates the stability and corrosion behavior of additively manufactured ceramics under hydrogen combustion, addressing degradation and thermal shock effects. This subproject focuses on developing and executing combustion testing scenarios and evaluating the long-term corrosion behavior of additively manufactured ceramics under hydrogen-related conditions,

- **Long-term aging** studies of porous alumina under both hydrogen and natural gas combustion atmospheres have been successfully completed, while hydrogen-aging of spinel ceramics is currently in progress.
- **Side-wall quenching (SWQ)** tests will be carried out using a custom-manufactured hydrogen burner, which is now fully built and ready for operation. The experiments are planned to start soon to investigate flame–wall interaction phenomena relevant to confined combustion environments such as gas turbines and internal combustion chambers.
- **Thermal-shock** testing plans and experimental design are finalized, and equipment construction is currently in progress to enable controlled cyclic heating and cooling experiments.

Long Term Aging Tests - Methodology

Fig 1: Images of sample before aging (a) and after 600h of aging (b)

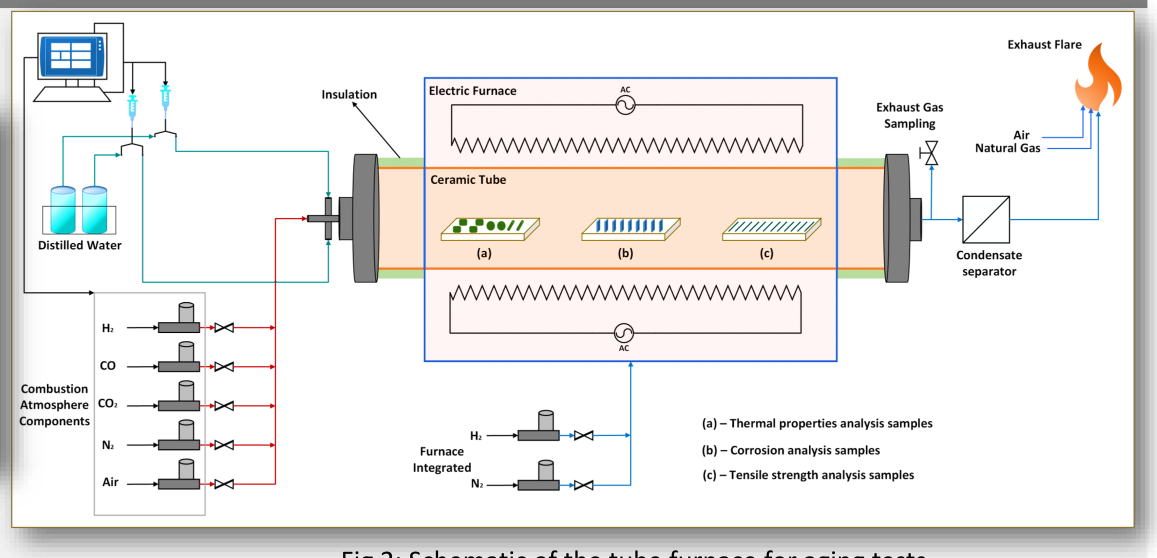

Fig 2: Schematic of the tube furnace for aging tests

- **Materials & Setup:** Two porous alumina types (PA-1: 41% porosity, PA-2: 39%) produced by additive manufacturing and sintered; tested in a high-temperature tube furnace at 1500 °C under controlled hydrogen and natural-gas combustion atmospheres.
- **Test Conditions:** Synthetic combustion gases supplied via mass-flow controllers with water-vapor addition; total exposure up to 600 h in 300 h intervals.
- **Analysis:** Mass-loss evaluation and SEM microstructural characterization performed to compare degradation under hydrogen vs. natural-gas conditions and between PA-1 and PA-2.

Long Term Aging Tests - Results

Mass Loss % of Porous Alumina Samples (PA-1 and PA-2) under Hydrogen (H2) and Natural Gas (NG) Combustion Atmospheres

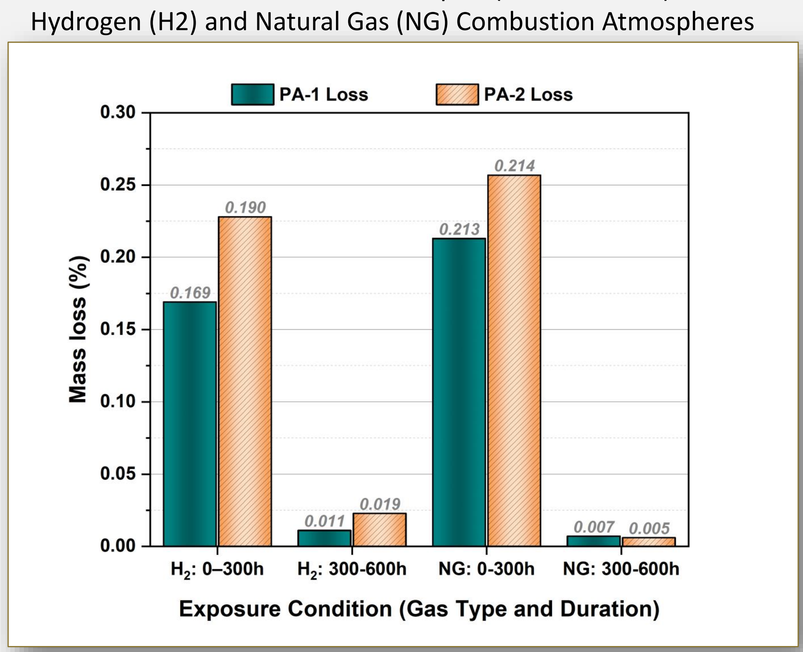

Fig 3: Plot of mass loss % vs exposure condition

Mass Loss per unit volume of Porous Alumina Samples (PA-1 and PA-2) under Hydrogen (H2) and Natural Gas (NG) Combustion Atmospheres

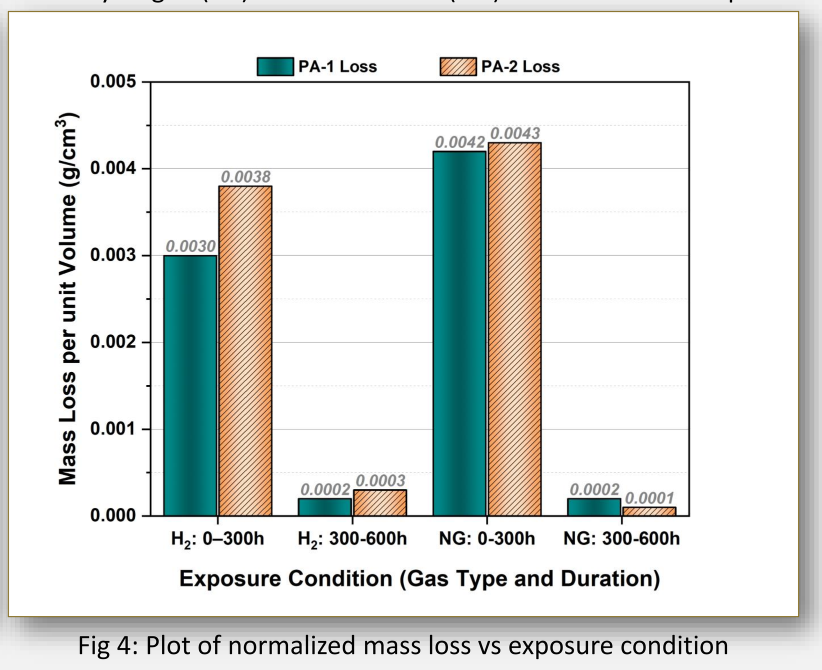

Fig 4: Plot of mass loss per unit volume vs exposure condition

- PA-1 and PA-2 remained stable after 600 h at 1500 °C, with PA-2 showing higher mass loss, especially in hydrogen.
- Initial exposure dominates degradation → most loss occurs in the first 300 h, followed by minor changes which indicates that a protective surface layer forms early, limiting further corrosion.
- SEM analysis revealed grain coarsening and localized pore growth, indicating gradual surface evolution without structural failure.

Flame wall Interaction

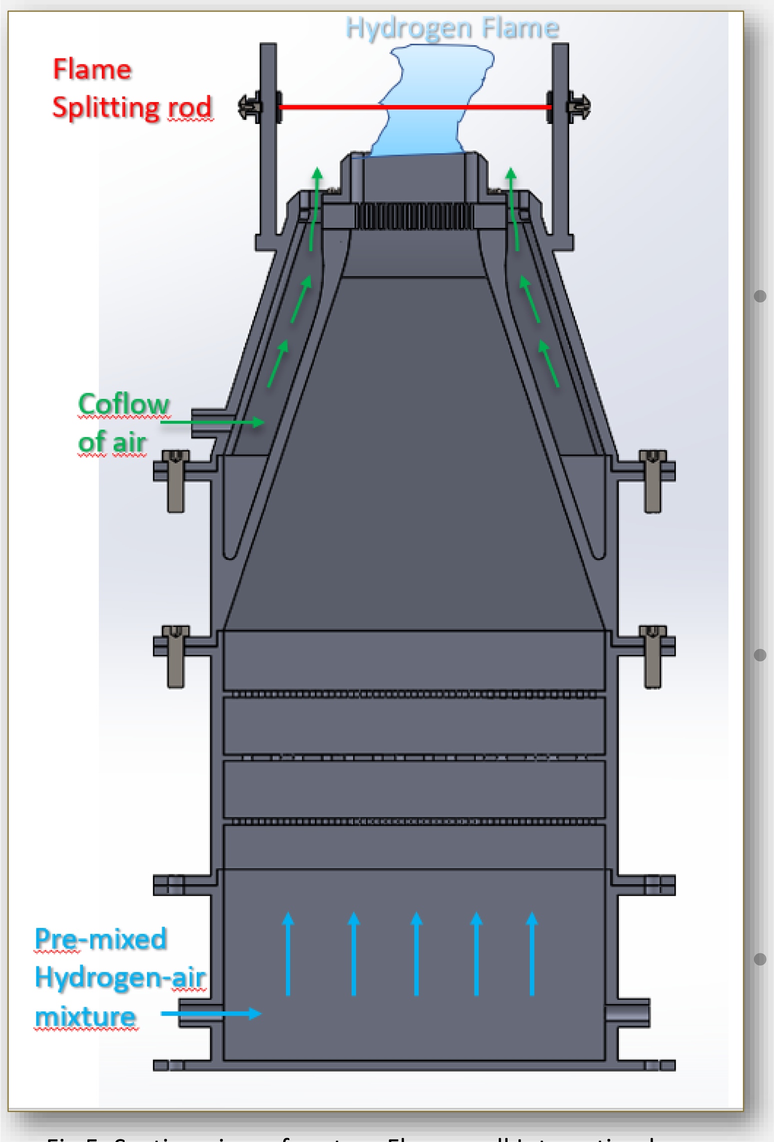

Fig 5: Section view of custom Flame wall Interaction burner

- A hydrogen burner with side-wall quenching geometry and optical access has been developed to study flame–wall interaction using OH-LIF diagnostics.
- Flow conditions (φ = 0.6 - 1.2) are precisely controlled by mass flow controllers, and a synchronized laser–camera system enables temperature-resolved OH imaging in the near-wall region.
- The optical layout and test plan are finalized, and alignment tests with baseline H_2–air flames are currently being prepared to verify signal quality.
- Next steps include temperature calibration, quenching layer mapping, and parametric evaluation across wall materials and operating conditions.

Thermal Shock Tests

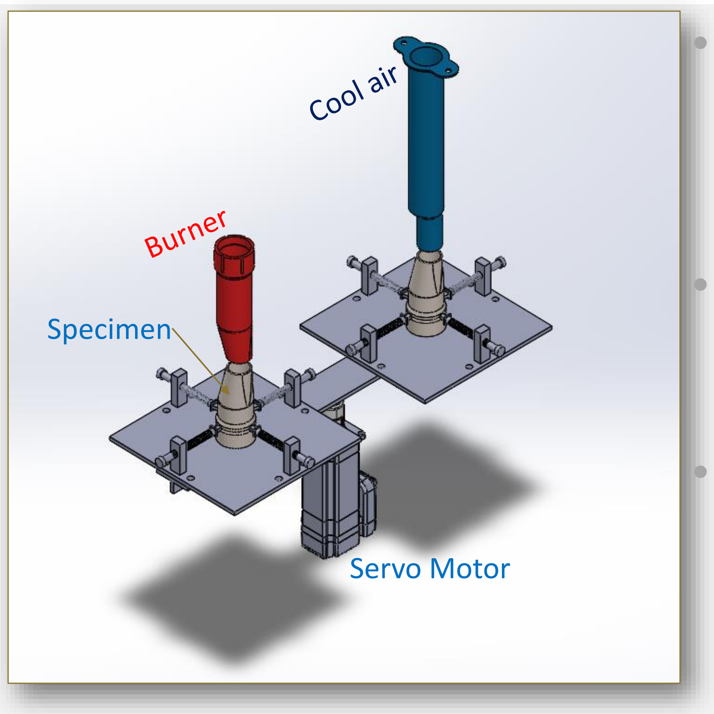

Fig 6: Thermal shock test rig design

- **Objective:** Evaluate the thermal-shock resistance of additively manufactured ceramics under rapid heating and cooling cycles.
- **Methodology:** Development of a rotating test rig with controlled flame exposure and air cooling.
- **Evaluation:** Compare crack initiation, Acoustic Emission activity, and surface morphology across materials and cycle counts to assess thermal fatigue and structural integrity.

Outlook

- Extended aging campaigns with spinel ceramics under varied combustion conditions are being conducted to establish comprehensive material stability correlations across different atmospheres.
- LIF investigations will include optical alignment, temperature calibration, and OH-field mapping to quantify quenching layer characteristics and support model validation.
- Thermal shock experiments following equipment completion, enabling a detailed correlation between crack initiation behavior, and surface degradation under cyclic thermal loading.

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