The Effect of Doping on the Fracture Toughness of YSZ in a Low Oxygen Partial Pressure Environment

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Solid oxide electrolyzers generate pure oxygen from oxygen-bearing gases such as carbon dioxide, water, and air. These electrolyzers that will generate oxygen from the carbon dioxide-rich atmosphere of Mars, and also from the evolved gases obtained from hydrogen or carbon reduction of the lunar regolith. There is a real need for developing better electrolyzer materials that offer superior thermal and mechanical characteristics as well as improved electrical performance. The electrolyte of the electrolyzer is a ceramic solid oxide such as yttria stabilized zirconia (YSZ). In order to develop structurally robust electrolyzers that would withstand the severe vibration and shock loads experienced during the launch and landing phases of the mission, it is essential to understand the damage initiation and consequent failure mechanisms and their relation to material composition and processing parameters. The objective of this research is to understand and quantify the relation between the loading/environmental conditions and the mechanical properties such as failure mode and strength and their relations to microstructures (thus processing parameters and choice of electrode and electrolyte compositions). In this presentation, the effects of dopants on the fracture toughness of YSZ in an environment with a low oxygen concentration are reported.

All the major studies conducted by NASA in the recent past, such as the 90-day study and the Staford Committee report, have identified the need for utilizing space resources (i.e., "living off the land") as an important and necessary part of future exploration of the solar system. Several studies have shown that oxygen production from the Martian atmosphere and from Lunar regolith as a key technology that can reduce the cost of both robotic and human missions. The production of oxygen from carbon dioxide and water is of importance for both propellant production as well as life support. For example, it would be highly desirable to have a closed loop life support system with oxygen reclamation in the transit vehicle to Mars as well as for extended stays aboard the Space Station. This research addresses the material issues related to electrochemical systems in the area of ISRU. Based on the knowledge learned from this research, superior materials will be developed with exceptional properties for improving the structural integrity of solid oxide electrolyzers. The improved electrolyzers would process *in-situ* materials to produce usable consumables in micro- and reduced gravity environments.

The presence of oxygen ion vacancies in the crystal structure of YSZ allows oxygen to be separated exclusively from an oxygen bearing gas, when a DC potential is applied. The DC potential is applied to the electrolyte through porous electrodes that are applied on both sides of the electrolyte. The electrode materials are typically platinum or a perovskite such as doped lanthanum chromite. The electrochemical cell thus formed is made fairly thin (50 to 400 microns) in order to reduce the ohmic losses across the cell. Hence, the electrochemical cell is a ductile/brittle/ductile (in the case of platinum electrode), a brittle/brittle/brittle (perovskite electrodes) or brittle/brittle/ductile (hybrid electrodes) thin layered structure with the YSZ layer as the load-bearing structural member. A YSZ layer of high fracture toughness is therefore desirable. Several approaches to increase the fracture resistance of YSZ by toughening are available. While m-ZrO_2 can increase the strength of YSZ, it also lowers its oxygen ion conductivity. Fine particles of partially stabilized zirconia and alumina, when added in small quantities, have been shown to provide increase in strength without degrading the electrical properties. Only limited amount of mechanical testing has been done measuring flexural strength thus far on toughened YSZ products. In this investigation, the amounts of partially stabilized zirconia, alumina, and Alkoxide were

systematically varied in the composition of YSZ. The resultant materials were placed in a low oxygen concentration, high temperature environment for thermal cycling. Before and after the thermal cycling, the fracture toughness of each material was evaluated using Vickers indentation method. The results showed that the addition of a small amount of dopants can result in a significant increase in fracture toughness.

The fracture toughness measured by indentation serves as a screening method in selecting the material composition and processing parameters. A well-coordinated experimental investigation is planned to develop a more fundamental, scientific understanding of the damage and failure characteristics of solid oxide electrolyzers under dynamic loading conditions at elevated temperatures with severe temperature gradients. The effects of microstructure on two key material properties –thermal expansion mismatch between the layers and the degradation of material strength and toughness in low oxygen concentration environment – will be thoroughly investigated. Dynamic fracture toughness and dynamic bi-axial flexural strength will be measured as a function of material composition and processing parameters. Optical and electron microscopy will be employed to identify the deformation mechanisms and failure modes, thus relating the mechanical properties to microstructures and material processing.