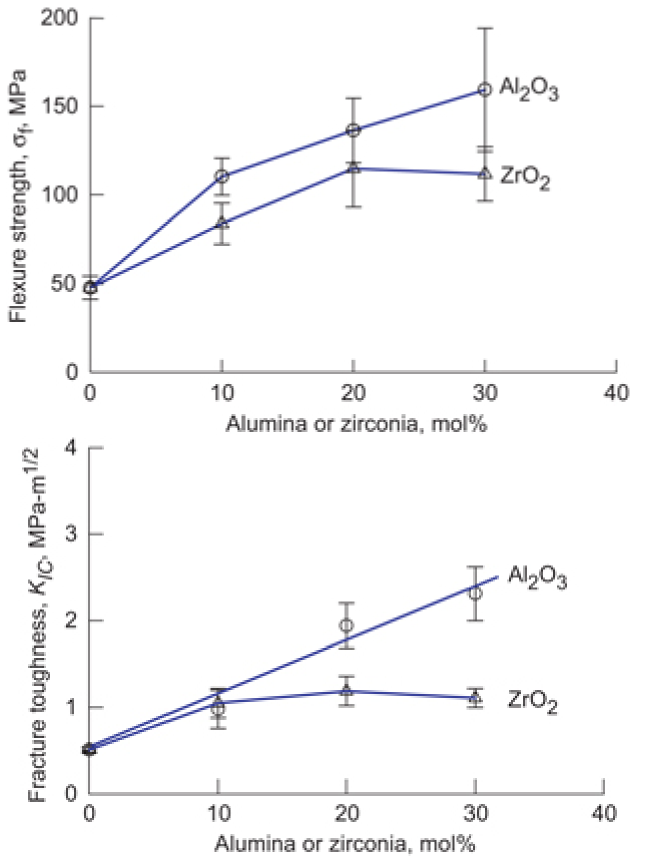
Strong, Tough Glass Composites Developed for Solid Oxide Fuel Cell Seals

A fuel cell is an electrochemical device that continuously converts the chemical energy of a fuel directly into electrical energy. It consists of an electrolyte, an anode, and a cathode. Various types of fuel cells are available, such as direct methanol fuel cells, alkaline fuel cells, proton-exchange-membrane fuel cells, phosphoric acid fuel cells, molten carbonate fuel cells, and solid oxide fuel cells (SOFCs). The salient features of an SOFC are all solid construction and high-temperature electrochemical-reaction-based operation, resulting in clean, efficient power generation from a variety of fuels. SOFCs are being developed for a broad range of applications, such as portable electronic devices, automobiles, power generation, and aeronautics.

SOFCs of two different designs, tubular and planar, are currently under development. Planar SOFCs offer several advantages, such as simple manufacturing and a relatively short current path, resulting in higher power density and efficiency than for the tubular design. However, planar SOFCs require hermetic seals to separate and contain the fuel and oxidant within the cell and to bond cell components together. The requirements for SOFC sealing materials are severe since the cells will operate at 600 to 1000 °C for thousands of hours, with sealing materials exposed to both oxidizing and reducing conditions. The seals must be chemically and mechanically compatible with different oxide and metallic cell components and should be electrically insulating. Also, they must survive cycling between room and operational temperatures.

Various glass and glass-ceramics based on borate, phosphates, and silicates are being examined for SOFC seals. Silicate glasses are expected to perform better than borate and phosphate glasses. A barium calcium aluminosilicate (BCAS) glass of composition (mol%) $35BaO-15CaO-5Al_2O_3-10B_2O_3-35SiO_2$ has been developed by the Department of Energy's Pacific Northwest National Laboratory (PNNL) for use as sealing material for planar SOFCs.

During thermal cycling of SOFC, the glass seal is prone to cracking. To alleviate this problem, PNNL asked for the help of researchers at the NASA Glenn Research Center in improving the strength and fracture toughness of this glass. To achieve this goal, we reinforced the glass with alumina platelets or 3 mol% yttria-stabilized zirconia (3YSZ) particulates. Panels of glass containing 0 to 30 mol% of the ceramic reinforcements were hot pressed and machined into test bars. Mechanical and physical properties, including four-point flexure strength, fracture toughness, elastic modulus, and density of the glass composites, were determined at room temperature.



Left: Flexure strength of BCAS glass composites containing various mole percent of alumina platelets or 3YSZ particulates. Right: Fracture toughness of BCAS glass composites containing various mole percent of alumina platelets or 3YSZ particulates.

Flexure strength (see the graph on the left) increased with an increase in alumina or 3YSZ content. For the same ceramic content, composites containing alumina platelets showed much higher strength than those with 3YSZ. Fracture toughness (see the graph on the right), measured by the single-edge v-notched beam method, showed similar large improvements. The increase in fracture toughness was much more significant for composites reinforced with alumina platelets than for those containing 3YSZ. Fracture toughness of the glass improved by 350 and 120 percent for composites containing 30 mol% of alumina and 3YSZ, respectively. Elastic modulus also increased with an increasing amount of reinforcement. The increase in elastic modulus was more predominant for composites reinforced with alumina than with 3YSZ. The addition of alumina did not have much effect on the glass density, whereas the composite density increased linearly with increasing 3YSZ content.

Thus, it has been demonstrated that reinforcing with alumina platelets can improve the strength of barium calcium aluminosilicate glass by as much as 250 percent and fracture toughness by as much as 350 percent. Leak tests for these glass composite seals are planned to be carried out at PNNL and should result in much improved seals for SOFCs.

This research was done under a Space Act Agreement between the NASA Glenn Research Center and the Department of Energy's Pacific Northwest National Laboratory.

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