Characterization and Modeling of Glass Tank Refractories at University of Missouri-Rolla (UMR) and Oak Ridge National Laboratory (ORNL)

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Furnace designers and furnace/refractory engineers recognize that increased optimization of furnace superstructure design and more appropriate refractories are needed as glass production furnaces are driven toward greater output and energy efficiency (and concomitant harsher operating conditions). The conversion to oxy-fuel from traditional air-fuel-firing is a means to meet these objectives. Refractories for both oxy- and air-fuel fired furnace superstructures can be subjected to high temperatures and stresses during service and may appreciably creep or subside if the refractory material is not creep resistant. Furnace designers can ensure that superstructure structural integrity is maintained or predicted if the creep behavior of the refractory material they are using is well-understood and well-represented by appropriate engineering creep models.

Several issues currently limit the abilities of furnace designers to choose the best refractory, optimize the engineering design, and predict the service integrity of refractory superstructures. First, published engineering creep data are essentially nonexistent for almost all commercially available refractories used for glass furnace superstructures. In addition, the various refractory suppliers provide the limited data that does exist. Unfortunately, suppliers typically conduct their mechanical testing, interpret the resulting data differently, and vary in their manner of reporting it, making it difficult for furnace designers to compare competing grades in an equitable fashion. Furthermore, the data is often not available in a form that can be used for furnace design or the prediction of long-term structural integrity of furnace superstructures.

The application of oxy-fuel fired furnaces for glass production has several benefits over the use of currently used regenerative furnaces. The NOx emission is an order of magnitude less for oxy-fueled furnaces compared to conventional regenerative furnaces, while the particulate level is much less as well. Additionally, the capital cost per ton of glass pulled is approximately 50% and 67% less for oxy-fueled furnaces compared to conventional regenerative and all electric furnaces, respectively. The downside to oxy-fuel furnaces is their higher operating temperatures and alkali partial pressures hasten corrosion, particularly in silica refractories. This necessitates that both creep and corrosion resistant refractories be used in their superstructure. The intent of this project was to quantify the high temperature creep and thermal conductivity of spinel refractories as one candidate class of materials for the replacement of traditional silica crowns. This could allow for the efficient design of furnace superstructures; thus, realizing the beneficial energy and pollutant savings oxy-fuel firing may yield.

Creep

Creep of refractory materials is normally measured for 25 or 50 hours after the application of load at a stress level of 0.2 MPa. In the case of the spinel materials there is very little creep at this stress level. Therefore, testing was performed at an increased stress level of 3.0 MPa. Even at this higher stress, there is minimal creep for the first 25 to 50 hours after the application of the load as shown in Fig. 1. Following the first 100 hours, the creep rate slightly increases with calculated creep rates found for fusion cast spinel of 1.44 x 10^{-6} /hr along the columnar microstructure in the chilled zone and 5.33 x 10^{-6} /hr for the bulk material away from the chilled zone (calculated during the last 100 hours of the test). The equipment used for the creep measurements at ORNL. is currently being modified to obtain even higher stress levels in an effort to measure meaningful levels of creep in this and other highly creep resistant materials.

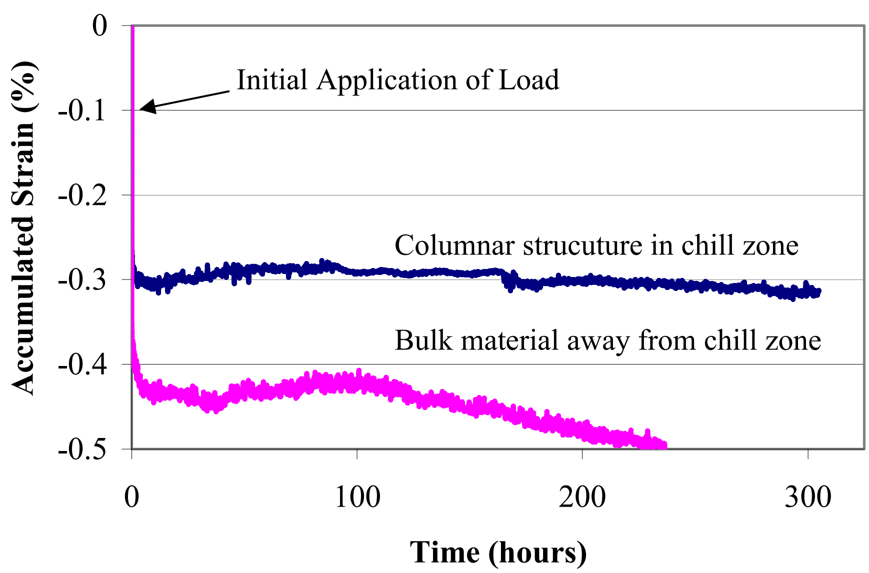

Fig. 1. Creep of fusion cast spinel at 1650ºC and 3.0 MPa

Thermal Conductivity

Thermal conductivity of the spinel materials was measured using the laser flash technique, which measures the thermal diffusivity of a material using a laser and the heat capacity, found by calorimetery. In conjunction with the bulk density, the thermal conductivity can then be calculated. Fig. 2 shows the thermal conductivity calculated for the bonded spinel from 100 to 1325ºC.

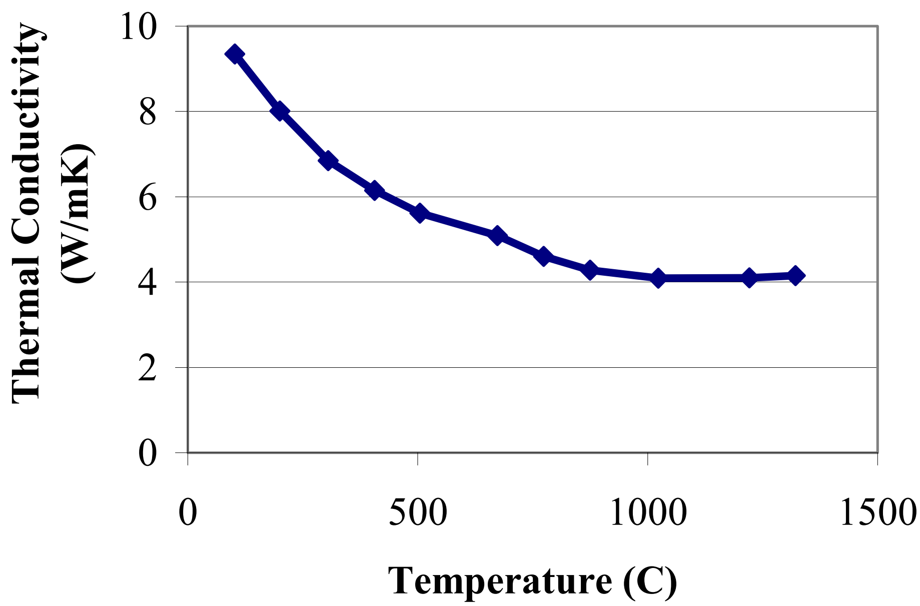

Fig. 2. Thermal conductivity of bonded spinel.

Corrosion

Corrosion of the spinel refractories was done in a simulative oxy-fuel glasstank at UMR. Cored samples were subjected to Na^+ levels of 200-400 ppm for 10 days at 1500ºC. This soda level has been shown to rapidly corrode silica crown refractories in similar tests. No reaction of the spinel was observed as shown in Fig. 3; however, free magnesia in the fused spinel reacted with silica to form glassy forsterite (Fo in Fig. 3). This was confirmed with x-ray diffraction; magnesia peaks reduced and glass increased slightly.

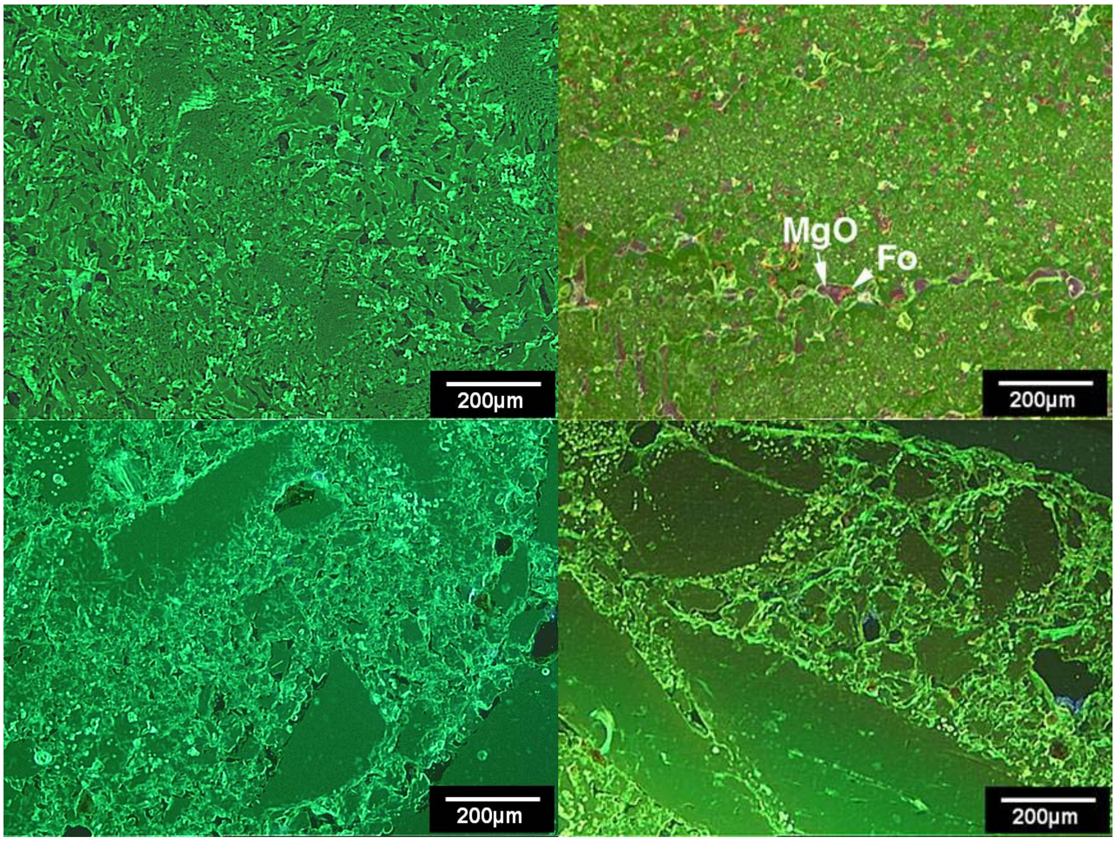

Fig. 3. Cathodoluminescence micrographs of fused spinel (top) and bonded spinel (bottom) before (left) and after corrosion (right).

Modeling

Models of the glasstank crown were created using ABAQUS finite element analysis software. Data for silica crowns previously developed at ORNL was used for the initial model. The model predicts the initial opening of cold face joints as seen on commercial crowns. Creep and corrosion slowly causes the cold face joints to close. Still remaining is the investigation of alumina and spinel crowns. Creep data is not available at the high compressive stress found at the hot face for any refractory materials hindering completion of the models.

Summary

Creep has been measured at a temperature of 1650^{o}C and a stress of 3.0 MPa, but needs to be measured at higher stress levels, up to 10 MPa and for longer periods of time, up to 300 hours. Additionally, thermal conductivity was measured for bonded spinel from 100 to 1325ºC, and it was found that spinel containing materials in this study were not corroded by soda; however, silica reacted with free magnesia. Finally, models of the glasstank crown were created using ABAQUS finite element analysis software and data for silica crowns previously developed at ORNL was used to validate the initial model. This model will be extended to the investigation of alumina and spinel crowns when additional data becomes available.