Toughening of Borosilicate Glass by Neutron Irradiation

Luke Gilde, Abigail Kittel, Rory O'Neill, Michael Hottinger, Amber Johnson

A. James Clark School of Engineering, University of Maryland, College Park, MD, 20742

Introduction

Silicate and borosilicate glasses are important materials for many applications; however, their low fracture toughness is detrimental in many situations. An experiment is underway to determine if it is possible to toughen borosilicate glasses by neutron irradiation. Samples of Schott Borofloat 33 are irradiated to thermal neutron fluences of up to $3*10^{16}$ n/cm^2 in the Maryland University Training Reactor (MUTR). Following the irradiation, the fracture toughness of the samples was determined by the indentation method.

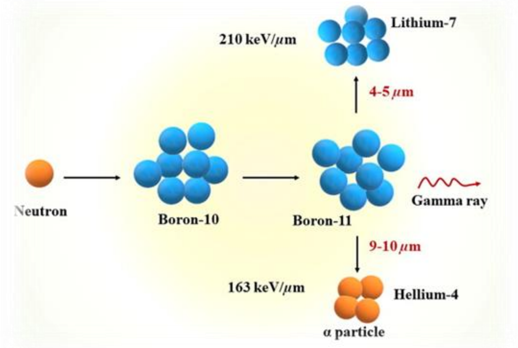
Preliminary results indicate that the toughness and hardness of the glass may be increased slightly by neutron irradiation.

Theory

There are several plausible mechanisms that may contribute to the toughening of the glass Firstly, radiation decreases the average coordination of boron in the glass lattice. This increases the plasticity of the glass and thereby increases its resistance to cracking. This effect could be caused by either neutron or gamma radiation. [1]

Secondly, the reaction of boron 10 with a thermal neutron can introduce small defects into the glass. When boron 10 absorbs a neutron, it breaks apart into lithium 7 and helium 4 atoms. These recoil with sufficient energy to create localized melting of the glass. As the glass cools it creates small defects in the glass.[1] These defects may form a network of preferred sites between which cracks will propagate; this will force the cracks to take a longer, more torturous path which dissipates their energy quickly, thereby halting crack growth and increasing the toughness.

Figure 1. The boron neutron capture reaction. [2]



Method

Samples of Schott Borofloat 33 plate glass were prepared from 6"x6"x0.25" plates. These 1"x0.5" tiles were irradiated in the MUTR Pneumatic Transfer System which allows small samples to be irradiated in a high flux environments within the reactor core. By varying irradiation times it will be possible to vary total neutron fluences on sample between $1.7*10^{14}$ and $3.1*10^{16}$ n/cm^2. Following the irradiations, short lived radionuclides are allowed to decay for several weeks.

Toughness was measured by the indentation method. Indentations were performed at 300 and 500 gram loads using a Wilson Tukon 2100 Vickers Hardness Tester. Indents and crack lengths were measured separately using an optical microscope.

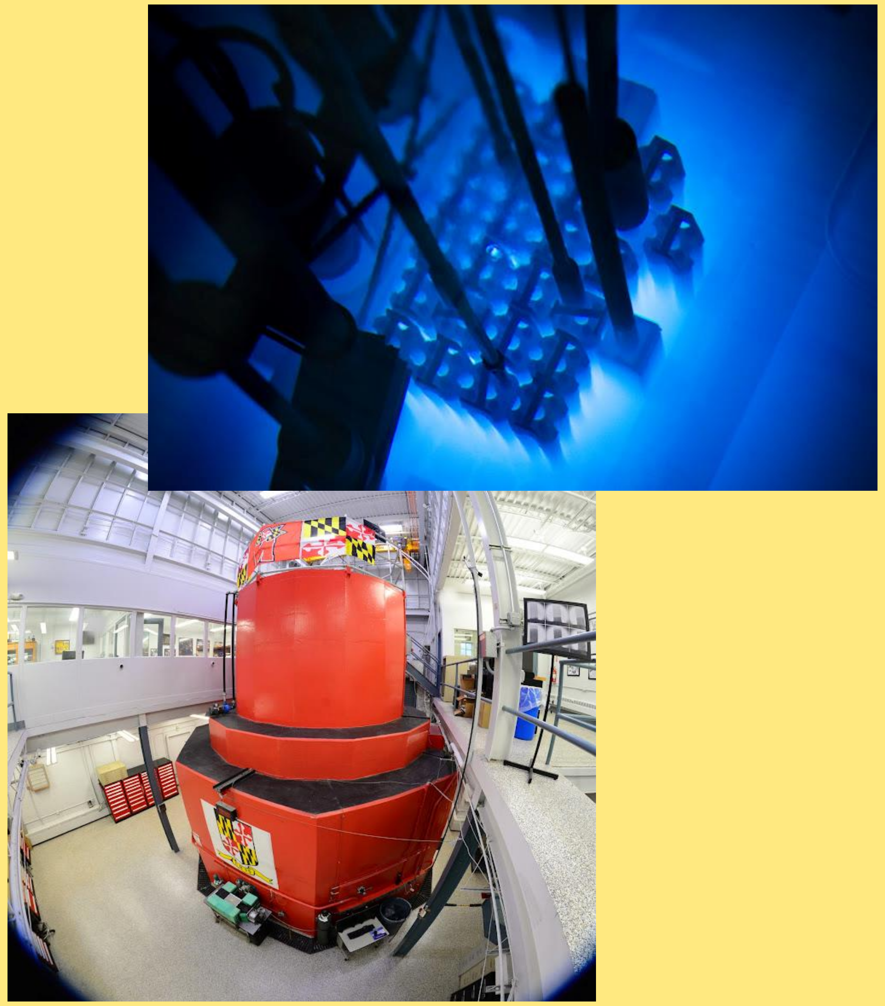


Figure 2. Top: The core of the MUTR at full power. Bottom: The MUTR Facility

Results

The baseline Vickers hardness and fracture toughness of the unirradiated Schott Borofloat 33 were found to be 5.8 ± .1 GPa and 0.82 ±0.04 MPa√m respectively. These agree well with previously published values of 5.4 GPa and 0.76 MPa√m. [3]

Following the irradiations, the glass samples were left for 2 weeks to allow the sodium 24 generated by neutron activation to decay. Gamma ray spectroscopy was then used to determine if any radioisotopes remained present. A number of fission products were observed indicating that the glass contained unexpected uranium and thorium. The concentration of these elements was found to be approximately 1 part per million. If this technique is to be used on a large scale, glass without any fissionable impurities will need be identified.

The irradiation darkened the glass considerably as shown in the photo below:

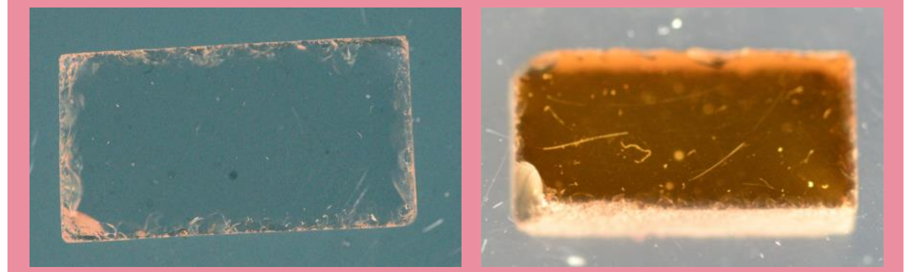


Figure 3. Glass sample before (left) and after (right) irradiation.

The hardness and fracture toughness of the irradiated glass samples was not significantly different than that of the unirradiated glass. There was a slight trend of increasing hardness and fracture toughness as neutron fluence increased as shown in the graph at right. Further studies will be necessary to see if this trend continues as neutron fluence increases. At high neutron fluences, the buildup of helium from neutron interactions with the boron may cause the glass to disintegrate. [4]

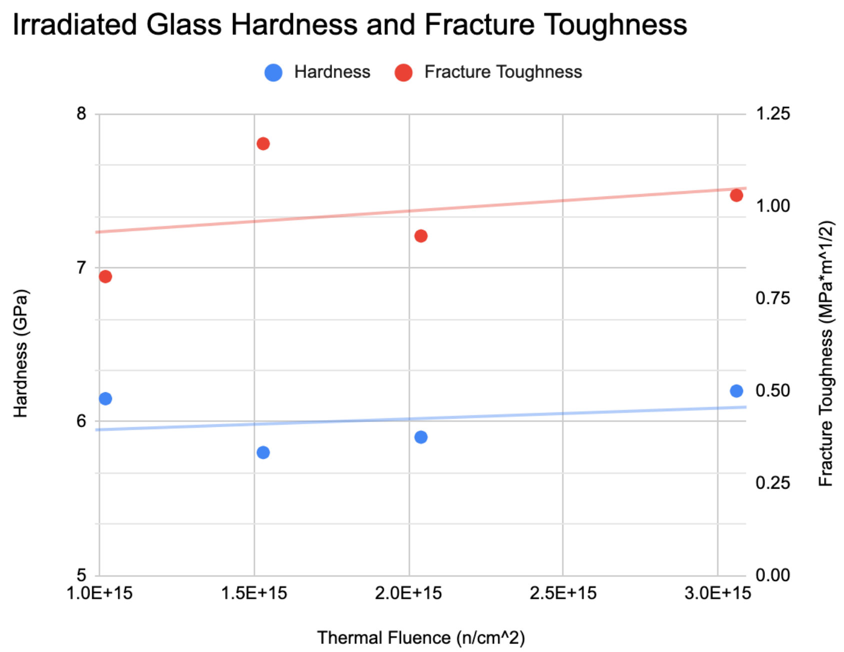


Figure 4. Hardness and fracture toughness of neutron irradiated Schott Borofloat 33 showing trends of slight increases as neutron fluence increases.

Conclusion

Thus far, insufficient testing has been completed to draw meaningful conclusions from this experiment. Work will continue to further characterize and understand the effects of irradiation on borosilicate glass. More samples will be tested to refine the results, and irradiation times will be increased to see if toughness continues to increase with higher neutron fluences. Irradiations will also be performed in a pure gamma environment to attempt to determine the role which the possible toughening mechanisms play.

Another key area of study will be to determine if the optical clarity of glass can be maintained under the influences of irradiation.

References

1. Effect of Radiation on Silicon and Borosilicate Glass; Allred, Clark L.; 2003
2. Boron Agents for Neutron Capture Therapy; Hu, Kuan et. al.; 2020
3. Surface Finishing of Micro-channels Using Low Kinetic Energy Abrasives; Jafar, Reza Haj Mohammad et. al.; 2014
4. Nuclear and Space Radiation Effects on Materials; National Aeronautics and Space Administration; 1970