Ion irradiation-induced changes in the properties of rock-forming minerals of concrete aggregates at high fluences

Vu-Nhut Luu [1*], Kenta Murakami [1], Hamza Samouh [2], Ippei Maruyama [2], Sho Kano [3], Kiyoteru Suzuki [4]
[1] Nagaoka University of Technology, [2] Nagoya University, [3] The University of Tokyo, [4] Mitsubishi Research Institute
*s165051@stn.nagaokaut.ac.jp

Abstract

To clarify the relationship between radiation-induced volume expansion and mineral structure, model materials of aggregates i.e. quartz and feldspars were studied. Results showed different expansion mechanism in quartz and feldspars owing to alkali ions though fluence dependence of expansion was similar.

Keywords: irradiation damage, amorphization, nanoindentation, cavity, silicate mineral.

1. Introduction

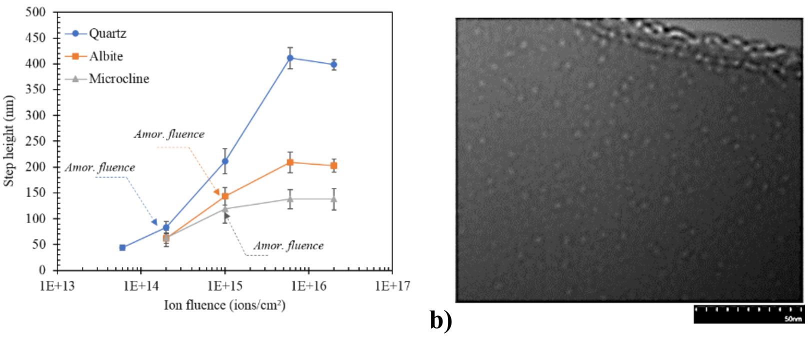
Concrete aggregates contain rock-forming minerals in which silicate minerals are most common and susceptible to Radiation-Induced Volume Expansion (RIVE). Since concrete are local products; and aggregates are diverse in composition, it is important to identify the environmental degradation factors affecting RIVE during long-term operation of nuclear power plants. Previous studies showed RIVE in neutron-irradiated concrete is affected by aggregate composition, especially silica content, and physical constraint during irradiation test [1]. Furthermore, alpha-quartz exhibited different RIVE under neutron and electron. This could be related to different forms of amorphous silica which is affected by constraint condition [2]. Thus, the effects of aggregate composition (i.e. mineral structures) and constraint on RIVE are important topics. Since density, stiffness, and hardness are important parameters for characterizing radiation-induced changes in irradiated minerals, the objective of this study is to demonstrate the changes in the properties of amorphized silicate minerals as a function of ion fluence for a better understanding of the relationship between RIVE and the mineral structures.

2. Materials and methods

Tectosilicates i.e. α-quartz and two feldspars (albite and microcline) are irradiated with 3MeV Si ions to high fluences, followed by measuring the step heights at unirradiated/irradiated interface and confirming amorphization layer by transmission electron microscopy (TEM). Hardness and Young's modulus of irradiated layer was measured by nanoindentation. Due to thin irradiated region (about 2μm) in comparison with sample thickness (>500μm), this region is constrained by surrounding undamaged matrix and volume change occurs mainly toward open surface.

3. Results

The fluence dependence of expansion was similar among the three minerals studied; however, the expansion mechanisms of the minerals differed (Fig.1). Quartz was quickly amorphized and then exhibited additional expansion by open-volume formation owing to constraining effect of surrounding undamaged matrix. The expansion of microcline and albite was mainly due to amorphization; however, a small additional expansion in albite was observed after amorphization. The change in hardness in the three minerals appeared to be a function of amorphization since no change occurred after a full amorphization. The Young's modulus decreased gradually with ion fluence; however, the change after amorphization was primarily dependent on alkali ions. In quartz, continued reduction of Young's modulus may be due to cavity formation, whereas it was not apparent in feldspar minerals.



a) b)

Fig.1. Fluence dependence of expansion (a) and open-volume formation in amorphized quartz at 1x 10^{15} ions/cm^2 (b)

References

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