Radiation-Induced Volume Expansion in Concrete Aggregate Minerals Studied by Ion Irradiation and Step Height Measurement

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Long-term radiation exposure can cause damage of concrete structures due to the volume expansion of the aggregate minerals. In this study, granite, sandstone, and tuff were irradiated with 2.8 MeV Fe^{2+} at room temperature to different level of ion fluences. Step height measurement was conducted to quantify the volume change. It was found that the swelling of all minerals saturated at around 300 nm. Tuff, which contains almost all silica, exhibited the fastest swelling, among others.

Keywords: Ion irradiation, radiation-induced volume expansion, amorphization, aggregate minerals

1. Introduction

Radiation-induced volume expansion is responsible for the long-term degradation in concrete structures. This event mostly occurs due to the amorphization of crystalline minerals, especially pronounced in α-quartz, which then causes the density to reduce. Ion fluence, that is proportional to the displacement per atom of crystalline minerals, is a primary indicator for in-service periods of concrete structures. Hence, it is favorable to use ion irradiation to study their radiation-induced damage. Every nuclear power plant uses different composition of aggregate minerals for the concrete structures. The fact that aggregate minerals have multiphases made it as a very complex process when it comes to radiation-induced damage. Therefore, to set a universal standard, further understanding about each mineral's behavior towards irradiation is needed. The objective of this study is to find out the effect of mineral difference on the fluence dependence of radiation-induced volume expansion.

2. Experiment

Received materials were three different aggregate minerals (i.e., granite, sandstone, and tuff) and their chemical compositions, analyzed by X-ray fluorescence, are shown in Table 1. Dominant content of these aggregates is silica, but granite and sandstone contain certain amount of alumina. The specimens were cut into plates, pasted on the aluminum basis, and were both mechanically and buff polished. The minerals were irradiated with 2.8 MeV Fe^{2+} ions at room temperature, with a fluence of 2 x 10^{14}, 1 x 10^{15}, 6 x 10^{15}, and 2 x 10^{16} ions/cm^2. For out-of-plane swelling, about half of each sample's surface were covered during irradiation to create an irradiated and an unirradiated region. Step heights of irradiated part were measured with laser microscopy. When measuring, straight lines were taken perpendicular to the border between the irradiated and unirradiated region. The distance between each line was set to be around 10 nm to get results in broad range.

Table 1. Chemical composition of aggregate minerals

	Na_2O (%)	Al_2O_3 (%)	SiO_2 (%)	K_2O (%)	CaO (%)	Fe_2O_3 (%)	Residual (%)
1	3.94	15.18	72.20	3.47	2.07	2.21	0.93
2	4.58	14.41	69.84	2.58	1.30	-	7.29
3	0.24	2.23	94.32	0.63	0.27	1.10	1.21

Note: 1 → Granite, 2 → Sandstone, 3 → Tuff.

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3. Results and Discussion

Clear steps were observable at the boundary between the irradiated and the unirradiated region. Fig. 1 shows the step height distribution of tuff with different ion fluences. Results indicated that the step height was distributed largely, and this occurred in granite and sandstone as well. However, in sandstone, step height was not detected in the lowest fluence due to the surface roughness and small level of swelling. The mean step height was almost the same as the average. Fig. 2 shows the ion fluence dependence in different aggregate minerals. Tuff, which contains of almost all silica, exhibited not only the fastest swelling among others, but also reached saturation point quickly. In 6E+15 and higher fluence, it was found that the swelling was saturated around 300 nm for all minerals.

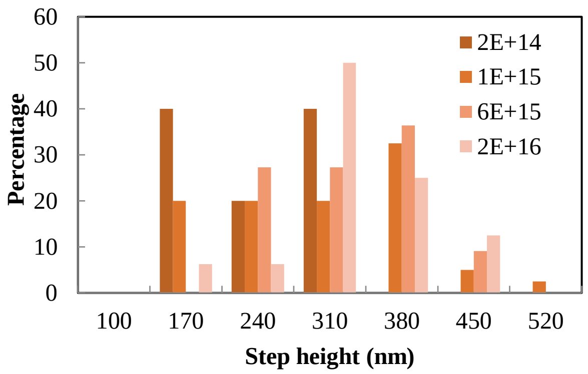

Fig. 1. Step height distribution of tuff induced by 2.8 MeV Fe^{2+} irradiation at room temperature with different ion fluences.

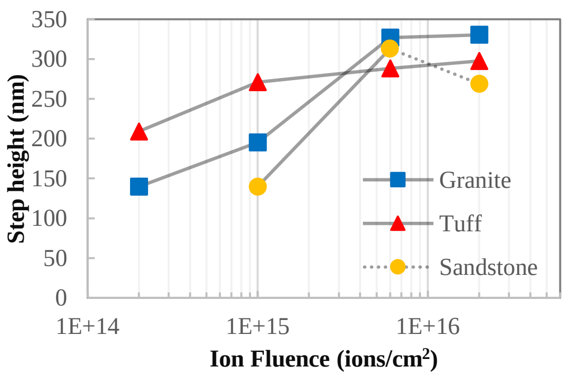

Fig. 2. Ion fluence dependence of average step height in different aggregate minerals induced by 2.8 MeV Fe^{2+} irradiation at room temperature.

4. Conclusion

The radiation-induced volume expansion in granite, sandstone, and tuff have been studied using Fe ion irradiation with different ion fluences. The results showed that higher ion fluence accelerated the volume expansion until the saturation point. The saturation level of all aggregate minerals was almost the same.

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