SWELLING OF ALPHA-SiO_2 INDUCED BY MEV IONS IRRADIATION: CRITICAL DOSE FOR SWELLING

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Abstract: The swelling effect was studied in α-SiO_2 crystal irradiated with 2MeV He^{2+} and 3MeV Si^{2+} ions using Tandem accelerators. Using profilometer and laser microscopy, the step height (represents the swelling) was measured in the boundary between irradiated and virgin area. The ion fluence induced swelling was found to be different with different ions depending on irradiation parameters. By converting the ion fluence to displacement per atom (dpa), the critical dpa for swelling was determined to be about 0.04 dpa, corresponds deposited energy of 2eV/atom. This is the dose required to form an amorphous region embedded in crystalline matrix induced by ion irradiation.

Keywords: Concrete degradation, stress relaxation, ion irradiation, irradiation defects

Introduction

Aggregates are well-crystallized non-metallic mineral structures which constitute about 70% by volume of concrete [1] and form a major component of the load-bearing structure in biological shielding. It is known that radiation induces considerable dimension change due to the amorphization of aggregate minerals [1]. Since aggregates are embedded in concrete, the amorphization process may build up a large internal stress (a few GPa) in concrete, which would lead to cracking or de-bonding between aggregates and mortar matrix during stress relaxation process. Quartz is the main minerals constructing aggregates which can expand up to 18% under irradiation. The purpose of this study is to clarify the integrated dose required to saturate volumetric expansion for aggregate minerals and the effect of irradiation parameters on swelling behaviour.

Experimental

The slices of quartz crystal with size of 5 x 10 x 0.5 mm, (0001)-oriented and one-side surface polished and irradiated with 2MeV He^{2+} and 3MeV Si^{2+} ions using Tandem accelerators. To measure step height, about half of the polished surfaces were covered by an aluminium foil during irradiation to create a boundary between irradiated region and virgin region, as Fig. 1. Step heights were measured using both laser microscopy and profilometer (Dektak 6M). To characterize the ion range and damage distributions, SRIM2013 package were used (http://www.srim.org). All calculations were performed in "Detailed Calculation and full Damage Cascades" mode with the displacement threshold energy, E_d= 25 eV for the all atoms.

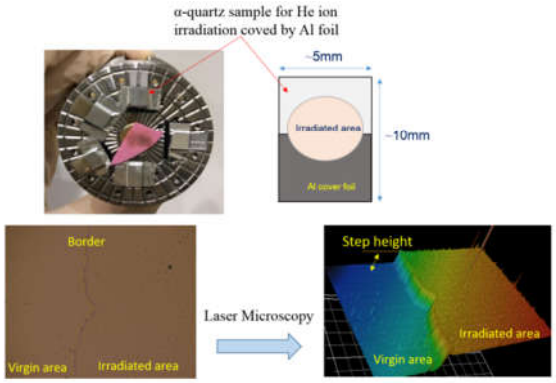

Fig.1 The sample setup for irradiation with 2MeV He ions and a typical step height measurement result obtained by Laser Microscopy after ion irradiation.

Results and discussion

Combining with [2], [3], the normalized step height versus ion fluences is presented in Fig.2, which shows the different amount swelling of different ions produce. Except the case of 2 MeV He ions, the slope of curves (represents the initial swelling rates) is quite similar, suggesting they have the same defect formation mechanism and the initial swelling rate is independent of ion energy and mass.

In order to clarify the integrated dose for swelling, the ion fluence was converted to the unit of displacement per atoms (dpa) (Fig. 3), which are calculated from number of displaced atoms per ion obtained from SRIM simulation. We found that the dose require for amorphization is about 0.04dpa corresponds to about 2eV/atom, indicating the dose required to form an amorphous region embedded in crystalline matrix induced by ion irradiation. This value is consistent with other researchers, F. Harbsmeier et al (1998) and S. Zhang et al (2018). We proposed that the swelling by ion irradiations occurs by two processes: (1) at first, swelling is induced by the amorphization, (2) after fully amorphized region formed, the swelling is continued by the viscous flow.

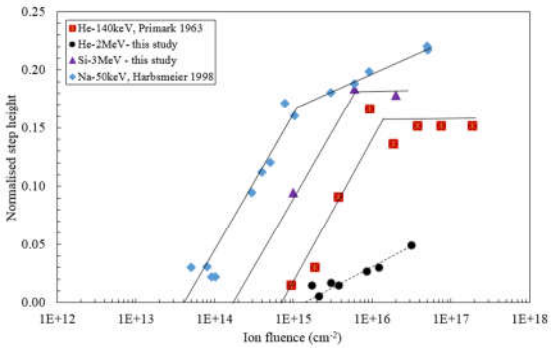

Fig.2 Normalized step height as a function of the fluence.

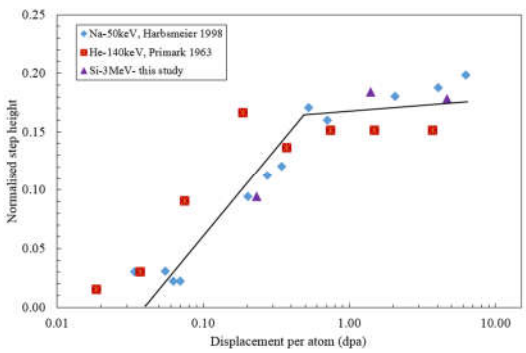

Fig.3 Normalized step height as a function of dpa.

Acknowledgment: This work is a part of the results from the "Japan Concrete Aging Management Program on Irradiation Effects (JCAMP) in 2018" sponsored by METI in Japan

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Hiện tượng phồng rộp ở tinh thể thạch anh (α-SiO_2) gây ra bởi chùm ion năng lượng cao: Liều chiếu tới hạn

Tóm tắt:

Báo cáo này nghiên cứu hiệu ứng phồng rộp xảy ra tinh thể thạch anh (α-SiO_2) khi bị chiếu xạ bằng chùm ion, với các năng lượng lần lượng là 2 MeV He^{2+} và 3 MeV Si^{2+} trên máy gia tốc hạt Tandem. Sử dụng máy đo biên dạng bề mặt và kính hiển vi laser, sự phồng rộp được đo ở đường biên giữa vùng chiếu xạ và không bị chiếu xạ. Thí nghiệm cho thấy liều chiếu ion gây ra hiện tượng phồng rộp của từng ion là khác nhau phụ thuộc vào thông số chiếu xạ. Bằng cách chuyển đổi đơn vị liều chiếu ion sang số lần dịch chuyển trên mỗi nguyên tử (dpa) được tính toán bằng phần mềm SRIM, liều dpa tới hạn được xác định nằm trong khoảng 0,04 dpa, tương ứng năng lượng hấp thụ là 2eV/nguyên tử. Đây là liều hấp thụ năng lượng cần thiết để hình thành một vùng vô định hình nằm trong tinh thể gây ra bởi chùm ion.

Từ khóa: sự xuống cấp của bê tông, giải phóng ứng suất, chiếu xạ ion, khuyết tật do bức xạ