Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS29-16 Room:304 Time:May 24 15:00-15:15

Fractal characteristic of fracture in glass or rock mineral by 3D X-ray CT measurement

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Because fracture geometry in solid rock affects greatly the seismic activity in that area (e.g. Oncel *et al.*, 2001; Dieterich and Richards-Dinger, 2010), it is necessary to grasp complexity of fracture distribution. They have been studied using fractal theory (e.g. Ohno and Kojima, 1992; Sukumono *et al.*, 1997). However these measurements have not considered three-dimensions heterogeneity of the fractures patterns. Actual fractures extend in space, moreover, many geological features including the growth pattern of earthquake rupture zones are statistically self-affine (Turcotte, 1989; Nagahama, 1994). So we should analyze the fracture geometry spreading in the space and measure them considering the anisotropy of fracture geometry.

In this study, we examined the fractal characteristics of fracture geometry of experimentally fractured mineral samples for anisotropy measurement using 3D micro X-ray Computed Tomography (CT) techniques. The samples are initially homogeneous borosilicate glass and single crystals of quartz. Samples were shaped into cylinders of 12.7 mm length and 6.0 mm diameter for glass, and 7.5 mm length and 3.0 mm diameter for single crystals of quartz. We performed fracture experiments under atmospheric pressure (uniaxial compression) and at a confining pressure (P_c) of 300 MPa with nominal axial strain rate of 5.0x10^{-4}/s using a Griggs apparatus at room temperature. In an experiment using the glass sample at P_c = 300MPa, brittle fracture occurred at differential stress of about 3.2 GPa, and bottom half of the glass sample was broken into fine fragments. In an experiment using the quartz sample, at P_c = 300MPa brittle fracture occurred at differential stress of about 7.0 GPa and top half of the sample was broken. Moreover, at uniaxial compression brittle fracture occurred at differential stress of about 2.5 GPa and bottom half of the sample was broken significantly. The obtained samples were scanned by micro X-ray CT at 3~10 x10^{-6} m spatial resolution using a 111~121 kV and 61~111 x10^{-6} A X-ray source. ImageJ was used for image processing. Then we measured the fractal dimensions of fracture on the space distributions using Box-Counting method (D_{BC}) and particle size distribution (D_{PSD}) for each slice of micro X-ray CT images sliced both perpendicular and parallel to the direction of maximum compressive stress (sigma 1 direction).

The fracture space distributions of the glass sample broken at P_c = 300MPa is fractal. D_{BC} of slices parallel to the sigma 1 direction were concentrated from 1.4 to 1.6 regardless of slices direction and location. Otherwise D_{BC} of slices perpendicular to the sigma 1 direction increase from 1.1 to 1.7 toward the highly fractured bottom side. D_{PSD} of slices perpendicular to the sigma 1 direction of the quartz sample broken at uniaxial compression similarly increase from 0.8 to 3.1 toward the highly fractured bottom side. Because the the fractal dimension of fracture surface roughness is proportional to the energy per unit mass required for fracturing (Nagahama and Yoshii, 1994), our result implies the possibility of heterogeneity in fracturing energy distribution even in highly homogeneous samples. We also compared D_{BC} with D_{PSD} in the glass sample by SEM images at the range from 1 to 100 x 10^{-6} m, where both showed the fractal nature. The relation between D_{BC} and D_{PSD} is 2 D_{BC} = D_{PSD}, that is not consistent with the theoretical formula 2 D_{BC} = D_{PSD} +1 which presumed isotropic fracture (Nagahama, 1992). Therefore, the present result shows that fracture distributions are possibly anisotropic indicating the necessity to consider the anisotropy of fractal characteristic in case of comparison with the fractal dimensions of different analyzing directions.

Keywords: fractal, 3D X-ray CT images, anisotropy, fracture geometry