Triaxial Compressive Property of Artificial CO$_2$-Hydrate Sand

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Carbon dioxide (CO$_2$) injection into marine sediments is considered to be a supplementary method for enhancing methane (CH$_4$) recovery from CH$_4$-hydrate reservoirs. It is essential to consider the geomechanical characteristics of CO$_2$-hydrate sediments to ensure sustainable CH$_4$-hydrate production using CO$_2$ injection. Experimental methods involving drained triaxial compression tests on artificial CO$_2$-hydrate sand specimens were developed. The mechanical property of CO$_2$-hydrate sand specimens was compared with that of CH$_4$-hydrate sand specimens. The difference in the mechanical property of CO$_2$-hydrate and CH$_4$-hydrate sand specimens was thought to be due to crystal growth and/or cavity occupancy in load-bearing hydrate.

INTRODUCTION

Gas hydrates consist of cagelike crystal structures made up of hydrogen-bonded water molecules surrounding guest molecules of gases (e.g., methane, ethane, propane, carbon dioxide (CO$_2$), and hydrogen sulfide). Methane (CH$_4$) hydrate existing in marine sediments or in permafrost regions worldwide is anticipated to be a promising source of natural gas (Makogon, 1981, 1982; Kvenvolden, 1988; Kvenvolden et al., 1993). The most effective procedure for CH$_4$ recovery from CH$_4$-hydrate reservoirs is considered to be a depressurization method in which the pore water pressure in sub-seabed layers is decreased, and CH$_4$ hydrate is dissociated into CH$_4$ gas and water in the reservoir. Since CH$_4$-hydrate dissociation is an endothermic reaction, the temperature of the sub-seabed layers decreases, resulting in a gradual reduction in the rate of CH$_4$-hydrate dissociation. Thus, heating the sub-seabed layers in the neighborhood of the CH$_4$-hydrate reservoir is a possible supplementary method for enhancing CH$_4$-hydrate dissociation and CH$_4$ recovery.

CO$_2$-hydrate formation in sub-seabed layers was suggested as a heating method (Ikegawa, 2008; Ikegawa et al., 2010). Because CO$_2$-hydrate formation is an exothermic reaction, CH$_4$-hydrate dissociation in the reservoir would be enhanced by CO$_2$-hydrate formation in the neighboring layers. Methods of continuous carbon dioxide injection and CO$_2$-hydrate formation are currently in the research and development phase.

It is essential to consider the geomechanical characteristics of CO$_2$-hydrate sediments to ensure sustainable CH$_4$-hydrate production using CO$_2$ injection because they may affect the stability of wellbores or other subsea structures, the occurrence of geohazards, CO$_2$ injectivity, and CH$_4$ gas productivity. However, greater knowledge of the mechanical properties of CO$_2$-hydrate sediments is required to predict the geomechanical response of sub-seabed layers to CO$_2$ injection.

There have been some earlier experimental studies concerning the mechanical property of CO$_2$-hydrate sediments. Wu and Grozic (2008) investigated the isotropic undrained behavior of CO$_2$-hydrate-bearing sands and demonstrated that the dissociation of even a small amount of CO$_2$ hydrate might lead to soil failure. Hyodo et al. (2014) obtained the triaxial compressive property of CO$_2$-hydrate-bearing sediment samples and noted that the production of CH$_4$ using CH$_4$-CO$_2$ replacement should not affect the mechanical stability of the reservoir. Hyodo et al. (2014) concluded that the failure strength of CO$_2$-hydrate-bearing specimens was close to that of CH$_4$-hydrate-bearing specimens on the basis of the triaxial compressive test results under a relatively high effective confining pressure (5 MPa). Hyodo et al. (2014) also showed only one data on the failure strength of a CO$_2$-hydrate-bearing specimen under an effective confining pressure of 1 MPa, interestingly suggesting that it was clearly smaller than that of CH$_4$-hydrate-bearing specimens although they did not mention it in their discussion. Wang et al. (2015) reported that the P-wave velocity of CH$_4$-hydrate-bearing sediments decreased with the CH$_4$–CO$_2$ replacement and inferred that this was because the mechanical properties of CO$_2$ hydrate differed from those of CH$_4$ hydrate.

In this study, experimental methods involving drained triaxial compression tests on artificial CO$_2$-hydrate sand specimens were developed. The triaxial compressive property of CO$_2$-hydrate sand specimens was obtained and compared with that of CH$_4$-hydrate sand specimens. The difference in the mechanical property of CO$_2$-hydrate and CH$_4$-hydrate sand specimens was discussed from the crystal-morphological viewpoint.