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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.

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KEY WORDS: Carbon dioxide (CO_2), methane (CH_4), hydrate, triaxial compression, strength, stress-strain relationship, elastoplastic constitutive model.