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Laboratory Study on Physical and Mechanical Properties of Hydrate Sediment Samples

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ABSTRACT

A series of tri-axial compression tests on tetrahydrofuran (THF) sediment samples were performed. Meanwhile, the ultrasonic wave and electromagnetic wave reflection properties were measured with ultrasonic transducer and time domain reflection technology (TDR). It is shown that P-wave, electromagnetic wave and stress-strain behaviors of hydrate sediment are affected by hydrate saturation. The shear strength increases and the stress-strain behaviors are very different when hydrate saturation increases. The physical properties obtained from P-waveforms and TDR data are very good complements for better understanding hydrate sediment samples.

KEY WORDS: hydrate sediment; shear strength; acoustic; reflection; hydrate saturation

INTRODUCTION

Gas hydrate is a potential source of fuel and usually formed under the relatively high pressure and low temperature conditions such as seafloor sediment and permafrost. The decomposition of hydrate leads to the shear strength of sediment decrease and subsequently may cause seafloor slide and offshore structures damage (Sultan and Cochonat, 2004). Previous researches（Winters and Waite 2007, Hyodo and Nakata 2007, Masui and Haneda 2005/ 2007, Yun and Santamarina 2007）show that the strength of hydrate sediment depends on hydrate saturation, type of sediment, confining pressure, temperature and strain rate.

It is noted that laboratory studies on stress-strain relationships and strength properties of hydrate sediment are mostly based on triaxial compression test results (Miyazaki and Masui 2011, Wei and Yan 2011).The acoustic properties of hydrate sediments through P-wave and S-wave measurement method are also reported by some researchers (Gei and Carcione 2003, Helgerd and Waite 2009, Li and Wang 2011). Winters and Waite (2007) studied both the mechanical and acoustic properties of Ottawa sand containing laboratory-formed methane gas hydrate and obtained rich information about hydrate sediment.

In South China Sea, geology survey and exploration indicates the existence of gas hydrate in clay sediment at the depths of 100-150m below the seafloor. Based on the remolded clay sediment from this area, a series of KHF hydrate samples are formed in laboratory with different hydrate saturation. And then the triaxial compression tests are performed along with the ultrasonic and TDR measurement. From a series of test data in laboratory, the stress-strain and strength properties of hydrate sediment samples associated with hydrate saturation and decomposition state of hydrate are obtained. Meanwhile, the acoustic and electromagnetic wave reflection properties are obtained from ultrasonic wave and TDR tests.

EQUIPMENT, TESTING METHODS

The laboratory apparatus (Fig.1) was developed by the Institute of Mechanics, Chinese Academy of Sciences. It can simulate high pressure and low temperature conditions that gas hydrate sediment will form. This integrated equipment consists of gas inlet and outlet controlling/measurement, triaxial compression, multi-technology measurement and data acquisition system. The tri-axial compression test system includes pressure cell, confining/back pressure, pore pressure and volume measurement system. The multi-technology measurement system is equipped with ultrasonic, TDR and electrical resistivity measurement technology. The apparatus can provide a maximum confining pressure of 14 MPa, maximum back-pressure of 10 MPa and a lowest temperature of –20˚C.

P-wave velocity (V_p) is measured by through transmission using 1MHz ultrasonic transducers that are located on the backside of each end cap of sample. A pulse is sent to the transmitting transducer and the received signal is amplified, digitized and recorded by a computer. The TDR probe is located on the lower end cap of sample, and the resistivity probe is on the upper end cap of sample. TDR measurement system consists of TDR100, CR1000 and LoggerNet. The TDR100 can generate a very short rise time electromagnetic pulse to a coaxial system, which includes a TDR probe for samples, and then digitize the resulting reflection waveform for analysis or storage.

The KHF hydrate clay sediment samples are formed in a different content of KHF and water. The remolded clay sediment, sampling from South China Sea, is fine clay and the grain size distribution is shown in Fig.2.

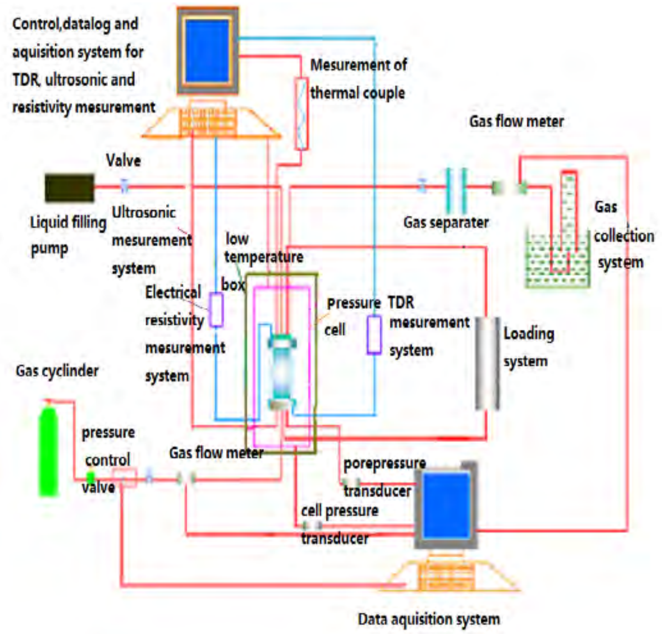


Fig. 1 Sketch of the tri-axial compression test equipment for gas hydrate sediment

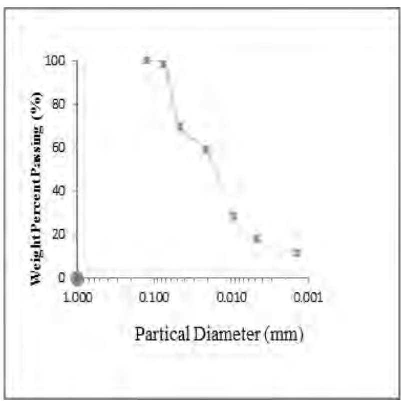


Fig.2 Grain size distribution

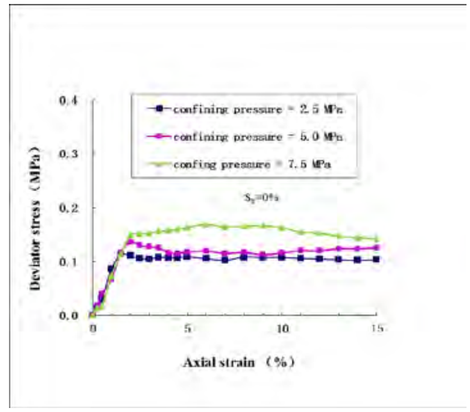
TEST RESULTS AND ANALYSES

Fig.3 shows deviator stress versus axial strain from triaxial compression tests conducted on clay sediment specimens which have different hydrate saturation (S_h) of 0%, 25%，50% and 100%. Table 1 lists shear strengths corresponding to the samples.

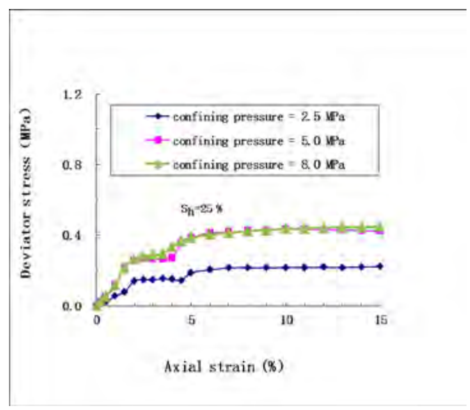
As shown in Fig.3 and Table 1, the triaxial compressive strength of hydrate sediment sample increases with the increase of hydrate saturation.When hydrate saturation is respectively equal to 25%，50% and 100%, the shear strength is corresponding equal to 2, 4 and 8 times as great as the non-hydrate (S_h =0%) sediment samples. Moreover, the stress-strain relationships of hydrate sediment samples are different when hydrate saturation is different. Fig.3d shows strain hardening phenomenon which is more apparent than Fig.3c, but Fig.3b shows the plastic failure characteristics. The change from plastic property to strain hardening behavior is reflected by the stepped stress-strain relationships. Fig.3a shows a slight brittle failure for non-hydrate sediment samples. So it is concluded here that hydrate can make not only the shear strength of sediment samples increase but also the stress-strain and failure behavior of sediment samples different.

Table 1 Strength parameters of KHF sediment samples

Strength coefficient	S_h= 0%	S_h= 25%	S_h= 50%	S_h = 100%
Cohesion (MPa)	0.04	0.08	0.15	0.3
Friction angle (^{0})	0.5	1.1	1.2	2.3



(a)



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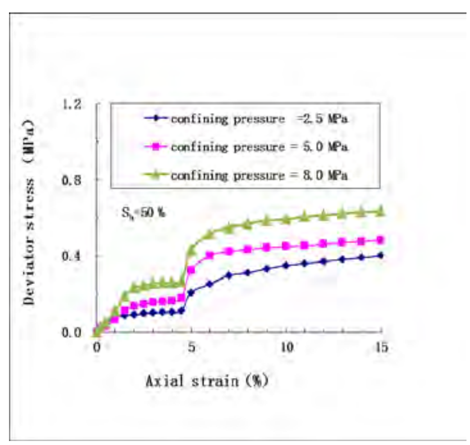
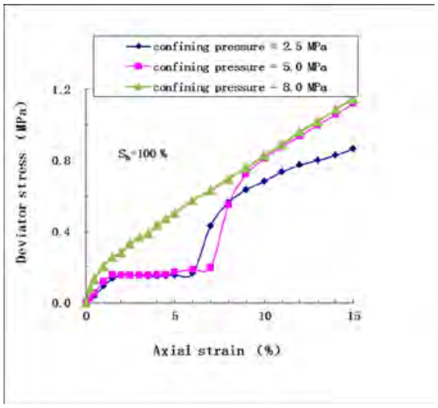


(c)



(d)

Fig.3 Stress versus strain when hydrate saturation is (a）0%, (b) 25%, (c) 50% and (d）100%

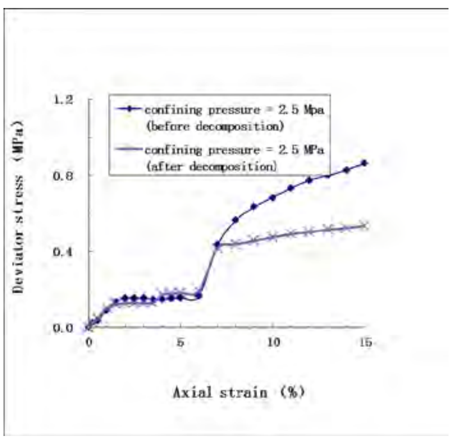
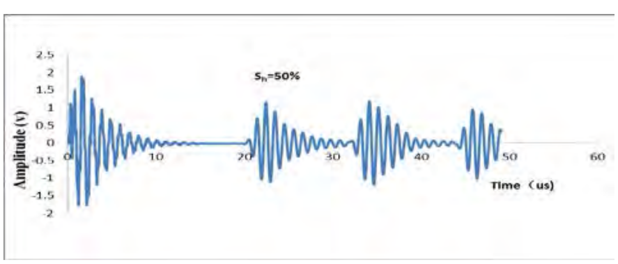
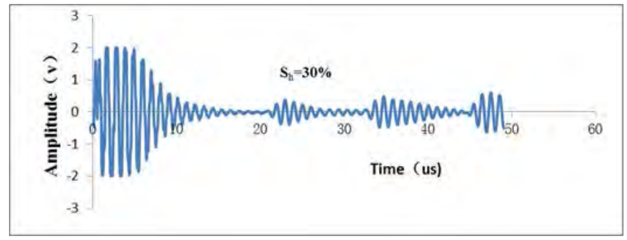


Fig.4 Stress versus strain for hydrate clay samples before and after hydrate decomposition

Fig.4 shows the comparision of stress-strain relationships of hydrate sediment samples before and after the decomposition of hydrate. The stress increses obviously with the strain when strain is greater than 7%. But when strain is less than 7%, the stress-strain relationships are almost the same. It indicates that hydrate has changed the structure of sediment samples and the stress-strain behavior of samples conforms this phenomenon.



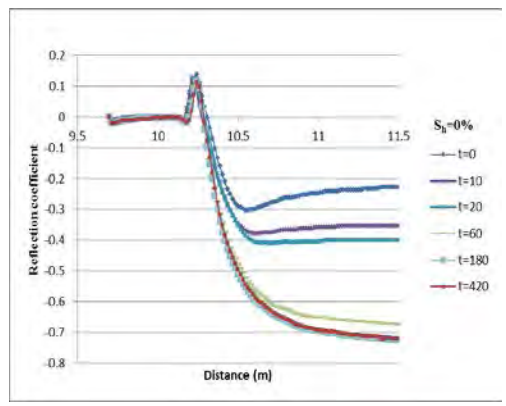
（a）



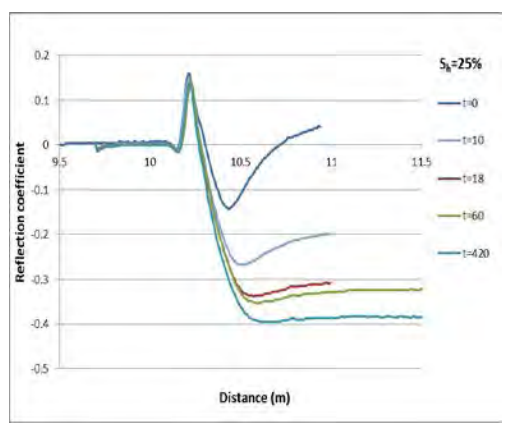
(b)

Fig.5 P-waveforms versus time when hydrate saturation is (a）50% and (b) 30%

The recoded P-waveforms of hydrate sediment samples with different hydrate saturation are shown in Fig.5. The caculated compression wave velocity is between 2010 m/s and 2210 m/s. Based on a series of ultrosonic wave mesurement results, there is a little difference of waveforms when hydrate saturation is different, and that depends on the accuracy of sound mesurement and the hydrate sediment samples. Because there is not any reflection waveforms for non-hydrate sediment samples tested, ultrosonic wave mesurement can be used to recognize if the hydrate sediment samples decompose.



(a)



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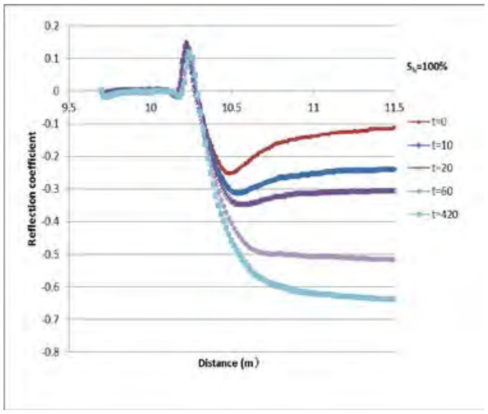

(c)

Fig.6 Reflection coefficient versus time (t/minutes) when hydrate saturation is (a）0%, (b) 25% and (c)100%

Similarly, TDR test data also reflects the differences of hydrate saturation. Fig.4 shows that the reflection coefficient (is related to water content) versus time. The non-hydrate sediment samples tend to a stable state more rapidly than that of hydrate sediment ones. The greater the degree of saturation, the longer time the decomposition of hydrate sediment samples needed. So, from the shape and size of reflection coefficient versus time, especially from the changes of reflection coefficient with time, hydrate saturation and the decomposition in sediment samples can be known. Further TDR measurements about different hydrate sediment samples will be done and experimental study achievements will be presented soon.

CONCLUSIONS

Based on a series of triaxial compression test, ultrosonic wave and TDR test data, the physical and mechanical properties of hydrate sediment samples to a specific area of South China Sea with different hydrate saturation are analyzed. When hydrate saturation is equal to 25%， 50% and 100%, the shear strength is correspondingly equal to 2, 4 and 8 times as great as the non-hydrate sediment samples. Moreover, the stress-strain behavior and failure mode are obviously different when hydrate saturation is different. Both the P-waveforms by ultrosonic mesuremnet and the reflection coefficent by TDR test are very good complements for better understanding the physical properties of hydrate sediment samples. The next step studies on the physical properties of hydrate sediment samples will have more improvements in aspects of ultrasonic wave and TDR measurement methods.

ACKNOWLEDGEMENTS

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