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LABORATORY INVESTIGATION ON AN GIANG SOIL MIXED WITH DRY CEMENT

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Abstract: The soil-cement mixing technology is a technique mixing the in-situ soil with cement to create a new material, soil-cement or soilcrete, having better engineering properties than those of the in-situ soil such as higher strength and higher stiffness. This study investigates laboratory behaviors of local soil mixing with dry cement that will be used to construct rural road pavement for light weigh trucks (<= 2.5 tons) in An Giang province. More than 200 soil cement mixing samples were made with various cement contents at different water contents and cured at different durations. The results indicate that local fine sand with a cement content of 10% or higher can improve significantly the compression strength and secant modulus of the in-situ soil at least 15 and 50 times at 21 curing days, respectively. Therefore, a 0.5-m sand mixed with 10% to 12.5% cement can create a pavement that allows light trucks traveling safely.

Keywords: *soil cement mixing, rural road, soil treatment, pavement, soilcrete*

1.0 Introduction

The Mekong Delta in the southern Vietnam, which is in the down stream of the Mekong River, has a network of rivers and is on a thick soft deposit layer. The Mekong Delta is often affected by annual floods from August to December every year. These characteristics of the Mekong Delta cause difficulty to develop the ground transportation system. According to An Giang Department of Transport, An Giang has a network of rural roads about 3,365 km, and about 1,850 km of rural roads that need to be urgently upgraded to serve local people traveling safely. The twelve other provinces in the Mekong Delta also have similar demand in developing rural roads.

Rural roads in the Mekong Delta are often built along rivers or canals because dredging materials of these rivers or canals provides fill materials to form road embankments. Subsequently, the rural roads are influenced by annual floods and are often submerged under the flood water level from October to December every year. Fill materials in the Mekong Delta to raise elevation of rural road surface above the food water are the most difficult problem in construction of rural roads. The local people have searched for new materials that can be used to construct rural roads economically and sustainably.

The in-situ soil mixed with dry cement is a technique to create pavement for temporary roads during construction (Kitazume & Terashi, 2013). In Vietnam, dry cement is also used to mix with medium clear sand to from sub-base and base layers for roads and pavement for rural roads (22 TCN 210-92). However, dry cement mixing the in-situ soils utilized as rural road pavement serving lightweight trucks has limit application. Therefore, this paper attempts to investigate mechanical behaviors of An Giang soils mixing dry cement to produce a new material having better engineering properties that can be used as pavement layer for rural roads to serve light weigh trucks (e.g., <= 2.5 tons). This study examined suitable parameters of cement mixing with local soils to form relevant soil cement mixing products (soilcrete) to make rural road pavement such as cement content, soilcrete thickness, water content, curing time, and soil types. All soil samples taken from a research site in My Hoa ward Long Xuyen City An Giang province were used to make soil cement mixing specimens in laboratory for the investigation of soilcrete behaviors.

2.0 Materials and Methods

2.1 Methods

The laboratory testing was conducted adopting the following standards: ASTM D2166, ASTM D1633, and TCXDVN 385-2006. The mechanical properties of soilcrete specimens were obtained using unconfined compressive strength test (UCS). A ratio of specimen high to its diameter is not less than 2.0. The load rate of UCS to create specimen displacement is less than 1 mm/minute. Unconfined compressive strength, q_u, and secant modulus of elasticity, E_{50}, are obtained using a stress-strain curve of each UCS test.

2.2 Soils

Soil materials used for the laboratory tests were collected at a field experiment site in My Hoa, Long Xuyen, An Giang. Fine sand containing organic material is a local material using for raising road elevation above the annual flood water level and clay is the top soil of the current rural road. All clay samples were taken from the top soil layer at thickness of 0.1 - 0.6 m in the centerline along the road. Sand samples were collected at providers of construction materials in An Giang. All samples were stored in plastic bags to preserve their natural water contents. Table 1 displays key properties of the soils used in this study.

Table 1: Properties of soil materials (LAS X475)

Properties	Notation	Unit	Clay	Fine sand
Sand (*d* < 2 mm)		%	7.3	39.8
Silt (*d* < 0.075 mm)		%	47.6	60
Clay (*d* < 0.002 mm)		%	44.1	-
Specific gravity	*Gs*		2.69	2.69
Liquid limit	*LL*	%	45	-
Plasticity Index	*PI*	%	22.4	-
Water content	*W*	%	34.5	9%
Wet unit weight	γ_w	kN/m^3	17.7	15.2
Dry unit weight	γ'	kN/m^3	13.2	14.1
Void ratio	e_o		1.04	0.87
Cohesion	*C*	kN/m^2	20.1	-
Friction angle	ϕ	độ	12^{0}32	21^{0}41
Unconfined compression strength	q_u	kN/m^2	68	-
Secant modulus of elasticity	E_{50}	MPa	2	11.43
Organic content		%	4.5	-
pH			6.05	-

2.3 Cement

PCB 40 Portland cement made in Vietnam was used to create soil cement mixing in the laboratory. The properties of the cement are printed in Table 2.

Table 2: The properties of PCB40 cement (TCVN 6260–2009)

Unconfined compression strength (MPa)		Setting time (hours)		Finer * (%)	Stability of volume (mm)	Content of SO_3 (%)
3 days	7 days	Starting	Ending			
18	40	3	8	8.6	6.7	1.2

* *Percent finer remaining on the seize >= 0,09 mm.*

2.4 Water

Tap water was used in the laboratory for raising water content.

2.5 Specimen preparation

All soilcrete specimens were prepared in PVC molds with dimensions of 120 ± 2 mm in height and 55 ± 2 mm in diameter, which is a ratio of height to diameter lager than 2.0 (ASTM, 2013; ASTM, 2007; Ministry of Construction,2006; Kitazume & Terashi 2013). Each mold was stabilized by three steel rings.

Soilcrete specimens were prepared at cement contents of 5%, 7.5%, 10%, 12.5%, and 15%; compacted at an equivalent energy of the standard proctor compaction test (e.g., 600 kJ/m^3); and with various water contents. The specimens were cured at the room conditions (e.g., temperature of 33-35^{0}C and humidity of 35%). The specimens were tested following the unconfined compression strength test protocol (UCS) at ages of 7, 10, 14, 21, 25, 28, 34, 45, 60, 90, 104, 108, and 110 days (TCXDVN 385-2006).

3.0 Results

More than 200 soilcrete specimens were made from An Giang clay and sand for the UCS tests. With the clay, specimens were mixed with clay at natural water content of 23.4% and a water content of 40%. For the sand, specimens were prepared at water contents of 9% & 13%. All specimens were cured at durations of 7, 10, 14, 21, 25, 28, 34, 45, 60, 90, 104, 108, and 110 days. Unconfined compression strength, q_u, of the soilcrete specimens varying with curing duration are shown in Figure 1. In general, q_u increases with increasing in curing time.

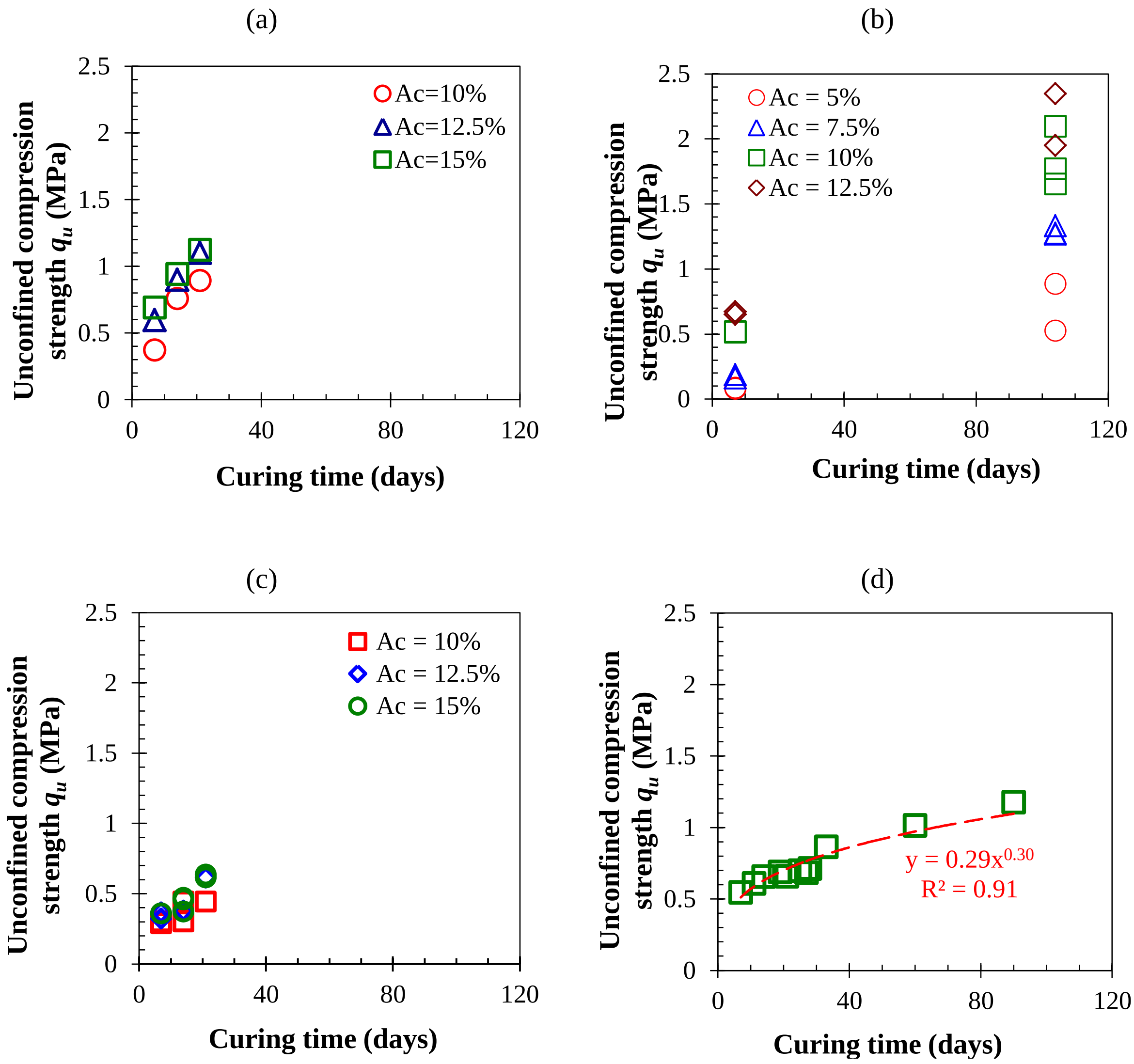

Figure 1: Unconfined compressive strength of soilcrete specimens varying with curing time, (a) Cement mixed with the clay at w = 23.4%, (b) Cement mixed with the sand at w = 9%, (c) Cement mixed with the clay at w = 40%, (d) 10% cement mixed with the sand at *w* = 13%

Variation of secant modulus of elasticity, E_{50}, of the soilcrete specimens with curing time are plotted in Figure 2.

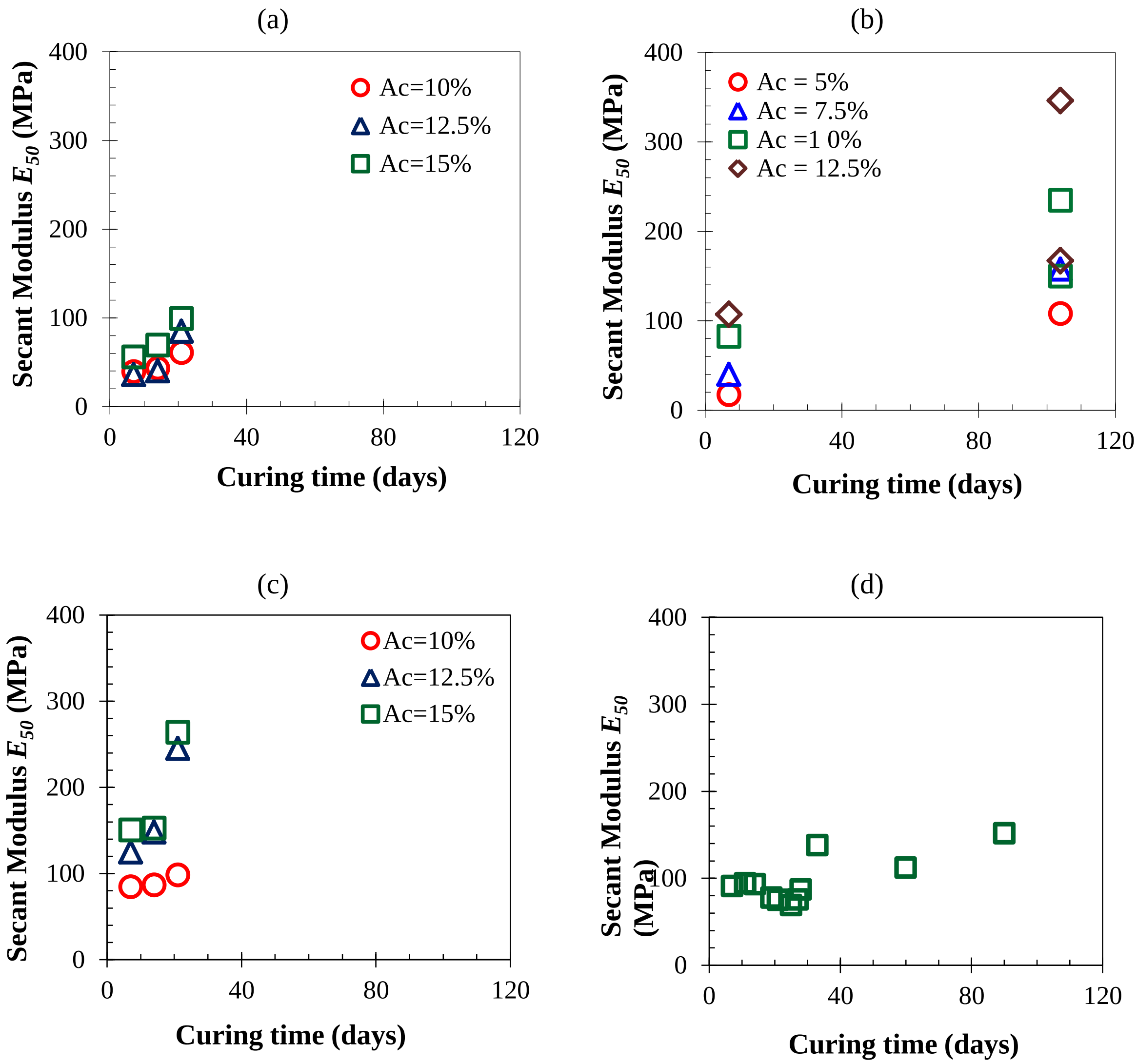

Figure 2: Secant modulus of elasticity, E_{50}, of the soilcrete specimens versus curing time, (a) Cement mixed with the clay at w = 23.4%, (b) Cement mixed with the sand at w = 9%, (c) Cement mixed with the clay at w = 40%, (d) 10% cement mixed with the sand at w = 13%

Figure 3 exhibits q_u of the soilcrete specimens developing with cement content and curing time.

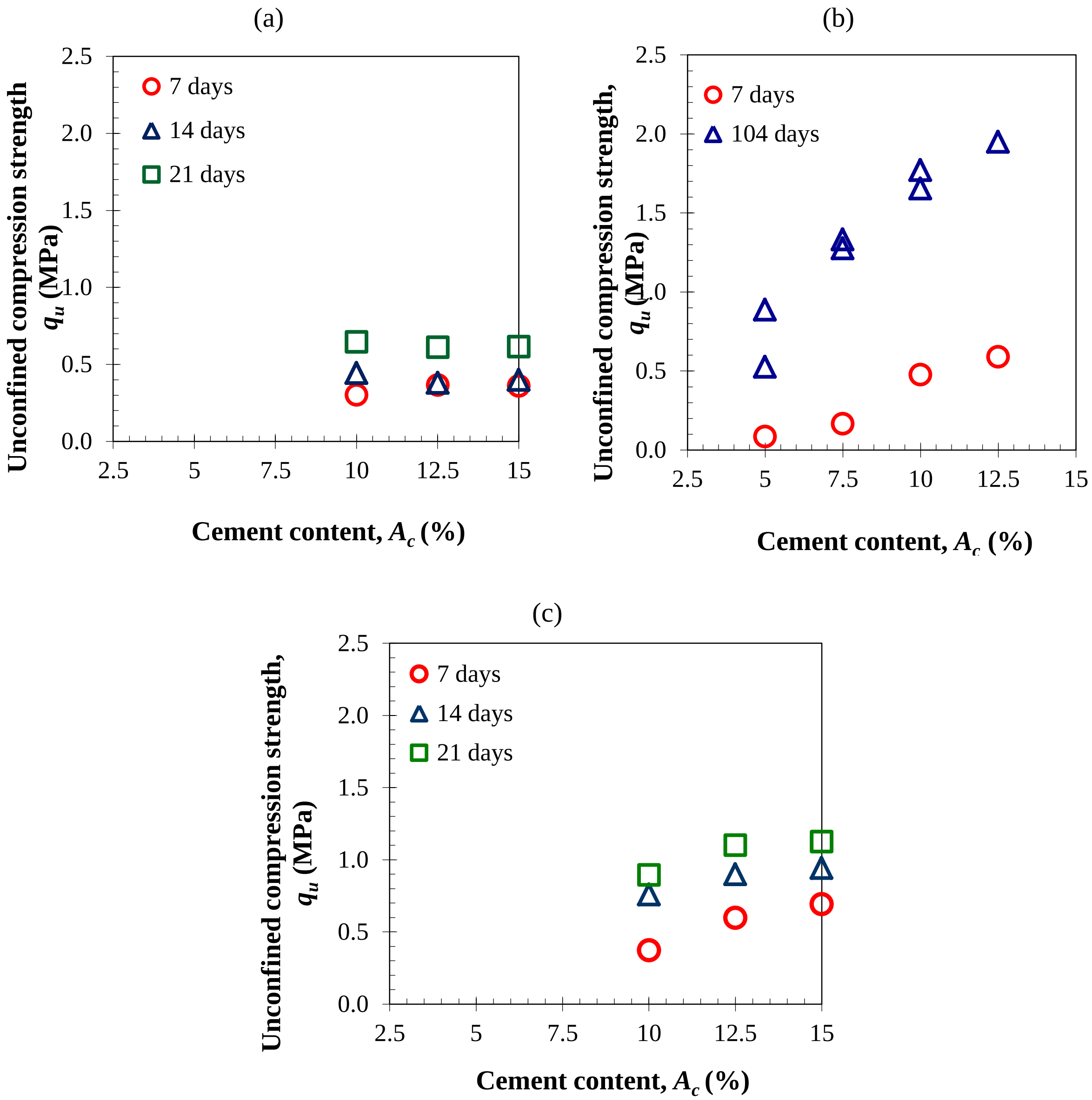

Figure 3: Variation of q_u with cement contents, (a) Cement mixed with the clay at w = 23.4%, (b) Cement mixed with the sand at w = 9%, (c) Cement mixed with the clay at w = 40%

The following Figure 4 illustrates q_u varies with water contents and curing time.

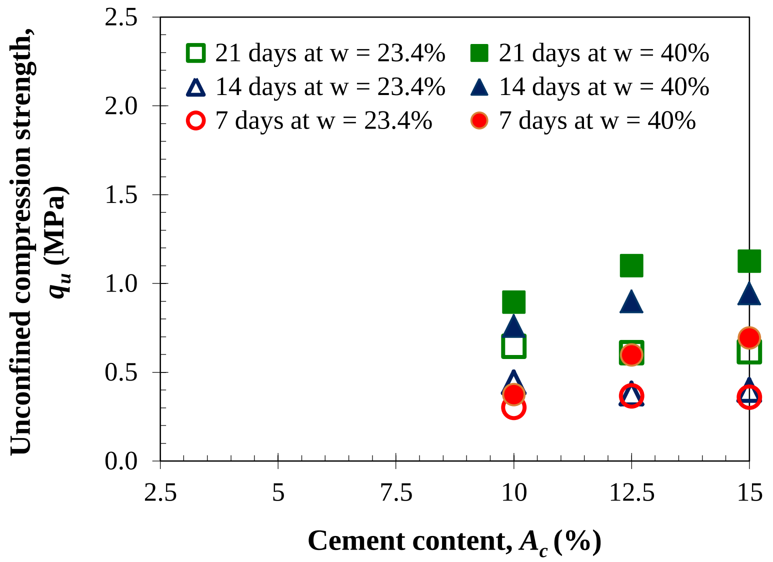

Figure 4: Unconfined compression strength changing with water contents and curing time

The q_u of sand and clay at a cement content of 10% versus curing time is shown in Figure 5.

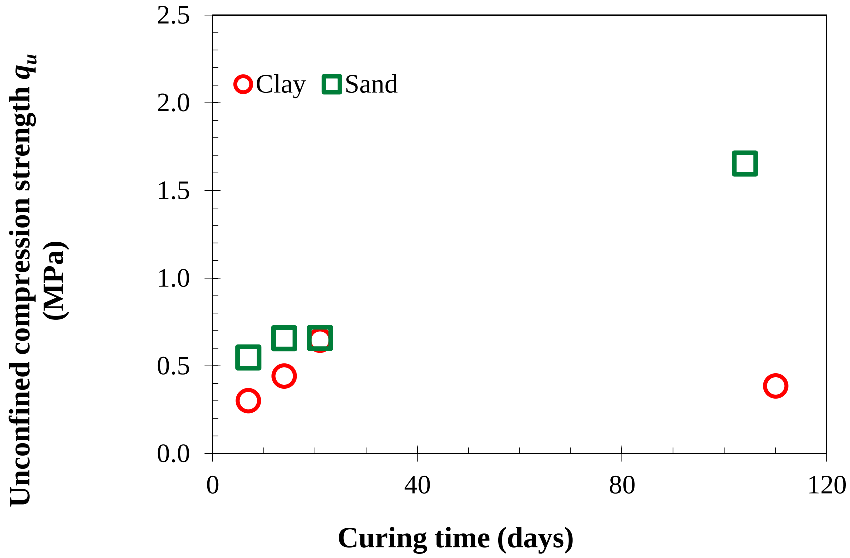

Figure 5: Unconfined compression strength varying with soil types

4.0 Discussion

4.1 Relationship of secant modulus of elasticity, E_{50}, and unconfined compression strength, q_u, of the soilcrete specimens

Figure 6 shows a relationship between E_{50} and q_u of the soilcrete specimens tested at various cement contents, soil types, water contents, and curing time from 7 days to 104 days. In general, E_{50} is mostly larger than 100. q_u, which argees well with Kamruzzaman (2002) that E_{50} was around 125. q_u, and also with Kitazume & Terashi (2013). At the same amount of cement, E_{50} of sand specimens is greater than those of clay specimens (Fig. 2a, b), and E_{50} increases with increasing in cement content (Fig. 2). It can be seen that E_{50} approaches 100 MPa for cement content of 10% or higher (Fig. 2, 7). This secant modulus can be used for pavement design (22 TCN 210-92 Vietnam code for design of rural roads), and E_{50} around 70 to 100 MPa is suitable for rural road pavement serving light weight trucks (e.g., 2.5 tons) in the Mekong Delta. Therefore, the local soils mixed with a cement content of 10% or higher have high potential application for construction of rural roads in the Mekong Delta.

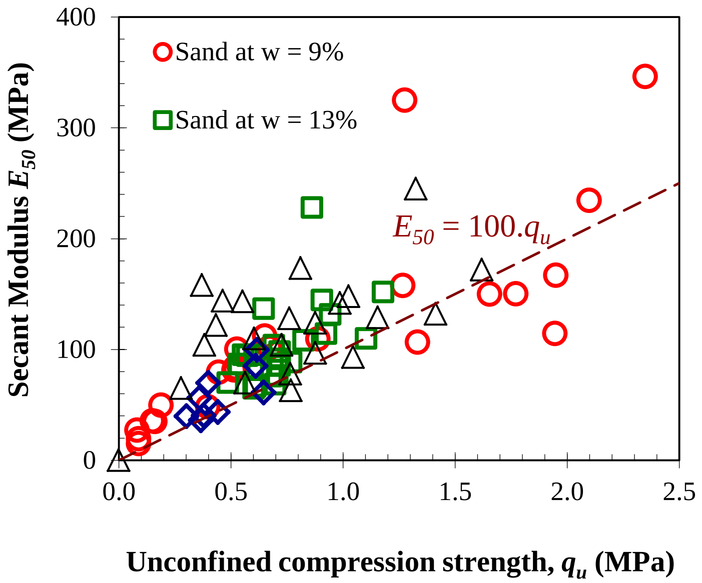

Figure 6: Relationship of E_{50} and q_u of the soilcrete specimens tested

4.2 *Effect of curing time to q_u of the soilcrete specimens*

Unconfined compression strength of all tested soilcrete specimens increases with increasing in curing time (Fig. 1). For the clay soilcrete specimens, q_u of the specimens with a cement content of 10% and water content of 40% increases 103% to compare with the untreated clay at curing times of 7-14 days (Fig. 1c). Similarly, the increases of the clay soilcrete specimens at cement contents of 12.5% and 15% were 50% and 36%, respectively (Fig. 1a, 1c). For the sand soilcrete specimens, q_u increases from 30% to 85% with the curing time from 1 to 2 months (Fig. 1b, 1d). It seems that the increasing rate of q_u of the sand soilcrete specimens was lower than that of the clay soilcrete specimens at the curing time up to 21 days. At the same amount cement content, q_u of the sand soilcrete specimens was higher than those of the clay soilcrete specimens. The cement hydration and pozzolanic reactions are two key soil cement reactions to form the compression strength of soilcrete products, and these reactions may take place for months or even for years (Kumruzzaman, 2002; Bergado *et al*., 1996).

4.3 *Effect of cement content to q_u*

A number of soilcrete specimens were made at cement contents of 5%, 7.5%, 10%, 12.5%, and 15% to investigate effect of q_u on cement content. Figure 3 shows the results of q_u versus the cement content. In general, q_u increases with increasing in cement content. Some sand soilcrete specimens and the all clay soilcrete specimens at cement contents less than 10% were totally broken after the specimens were removed out of the molds. The results indicate that cement content of 10% or higher should be used to create soilcrete. The q_u of the clay soilcrete specimens increased slowly with increasing in cement content up to 15% (Fig. 3a, 3c). On the contrary, q_u of the sand soilcrete specimens increased significantly with increasing in cement content (Fig. 3b). q_u increased 89%, 109%, and 18% with increasing in *Ac* of 5-7.5%, 7.5%-10%, and 10%-12.5%, respectively.

4.4 *Effect of soil water content to q_u of the soilcrete specimens*

The results indicate that moisture content of untreated clay soil is strongly affected to q_u than that of sand soil (Fig. 4, 1b, 1d). q_u of the clay soilcrete increased by 45%, 93%, and 104% when the water content increases from 23.4% (natural water content) to 40% (Fig. 4). q_u of the sand soilcrete at cement content of 10% and curing time of 7 days (Fig. 1b, 1d) was insignificant variation at water contents of 9% and 13%. Cement hydration and pozzolanic reactions of soil cement need water in pore voids to create cementatious products or soilcrete with better engineering properties with time (Kamruzzama, 2002; Tan *et al*., 2002). For clay due to fine grain size, water in pore voids and mixing speeds up the hydrated and pozzolanic reactions.

4.5 Effect of soil types to q_u of the soilcrete specimens

At the same conditions of testing such as cement content and curing time, q_u of the sand soilcrete was greater than that of the clay soilcrete (Figure 5) (Kitazume & Terashi, 2013). High clay fraction is high surface area and more mixing energy is needed to increase contact cement to soil grain. Thus, higher amount of cement is needed to mix with clay soils to have equivalent strength of sand soil. Bhattarcharja & Bhatty (2003) reported that higher plasticity soil (or PI) mixed with cement forms lower compressive strength that low plasticity soil.

5.0 Conclusions

More than 200 soilcrete specimens were made in the laboratory from the both local clay and local fine sand collected in My Hoa - An Giang mixed with various cement content and cured at different curing time to investigate soilcrete characteristics. Unconfined compression strength and secant modulus of elasticity of soilcrete specimens were obtained using unconfined compression tests. The results indicate that cement content of 10% or higher should be used for soil cement stabilization. Secant modulus of elasticity can be about 100 times unconfined compression strength. Unconfined compression strength of soilcrete at cement content of 10% or higher is greater 15 times than that of the untreated soils. Sand soilcrete is less sensitive to moisture than clay soilcrete.

6.0 Acknowledgements

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