コンクリート工学年次論文集, Vol.35, No.1, 2013

- Technical Paper -

SOFTENING BEHAVIOR OF CEMENT TREATED SAND

Kh. Adeel TARIQ *1 and Takeshi MAKI *2

ABSTRACT
Cylindrical specimens were casted by using cement (high early strength), sand and limestone powder for water to cement ratio (W/C) of 100, 130, 150, 170 and 190 %, cement to sand ratio (C/S) of 30%, limestone powder to cement ratio (L/C) of 130% by weight, and their softening behavior was investigated. The influences of material strength on compression fracture zone length and tensile fracture energy are investigated. Results have indicated that compressive strength of cement treated sand is independent of the size of the test specimen and variation in fracture energy is observed.
Keywords: Cement, Sand, Limestone powder, Compression fracture zone length, Tensile fracture energy

1. INTRODUCTION

The characteristic of the ground can be improved in order to facilitate construction process, to permit the adoption of increased allowable bearing pressure or to reduce settlement under a given foundation loading. Foundations for buildings can be placed at shallow depth, if soil close to the ground possesses sufficient bearing capacity. If top soil is weak or soft, the load from superstructure has to be transferred to deeper and firm strata. For such conditions pile foundation is used. Another possible approach is to use ground improvement techniques. Mixing of sand with cement is one of the possible ways to improve the foundation conditions especially for sandy soils. This technique is gaining popularity these days because of its relatively ease of use. However, long term behavior of cement treated sand has not yet been clarified.

Cementation plays a significant role in the engineering behavior of soils, and has been investigated by engineers around the world. Cement content does increase the peak strength of the treated soil, it also increases the stiffness thereby reducing the strain at which failure occurs [1]. Mechanical properties of most cement stabilized soils change over time; therefore the time-related performance of such treated soils is essential in understanding their durability and long-term effectiveness [2].

The viscosity of cement-based material can be improved by decreasing the water/cementitious material ratio or using a viscosity-enhancing agent. It can also be improved by increasing the cohesiveness of the paste through the addition of filler, such as limestone powder. The use of limestone powder improves the properties of fresh and hardened concrete such as workability [3]. For a fixed water content, high powder volume increases interparticle friction due to solid–solid contact. This may affect the ability of the mixture to deform under its own weight and pass through obstacles [4].

When concrete fails, damage usually concentrates in a narrow region in the structure. The localization behavior can influence the structural behavior, especially the post-peak behavior. Therefore, the fracture zone and the localization behavior have to be clarified for accurate understanding of the structural behavior up to the failure.

Strain softening of concrete occurs when microcracks which begin before the peak strength coincides to form a zone of damage (Fig. 1), weakening the concrete, so its load carrying capacity starts diminished, which ultimately leads to complete collapse. Additional deformation of zone of damage weakens it further and continued softening occurs. When specimen is short, damage appears to be concentrated in entire length.

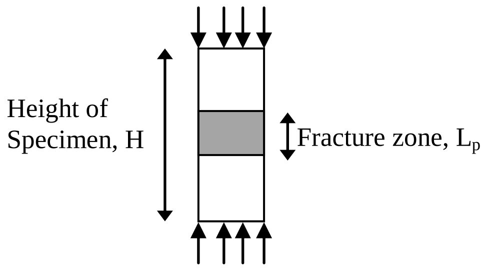


Fig. 1 Fracture zone length

Specimen geometry and boundary conditions will also affect the strain softening behavior because they affect the size and shape of fracture zone relative to overall specimen; investigating these influences is beyond the scope of experimental work presented here.

In the softening region, the damaged or fracture zone continues to strain while the undamaged zone elastically unloads. The undamaged zone only exists if the length of the specimen is greater than the damaged zone length. In the compression damage zone or failure zone model proposed by Markeset and Hillerborg, the

*1 Ph.D. Student, Dept. of Civil and Environmental Engineering, Saitama University, JCI Member
*2 Associate Prof., Dept. of Civil and Environmental Engineering, Saitama University, JCI Member

softening behavior in the damaged zone is due to a combination of longitudinal tensile cracking and the formation of a localized inclined shear band [5]. The relationship between compression fracture zone length (mm) and compressive strength of concrete (MPa) is as follows [6]:

$$L_p = \frac{1300}{\sqrt{f_c}} \tag{1}$$

This paper describes the compression fracture zone length and tensile fracture energy of cement treated sands. A method to measure the compression fracture zone length and tensile fracture energy for cement treated sands is presented.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

The experiments were carried out under controlled loading conditions and the total average strain is measured externally by using transducers which were set between loading plates. Test variables were W/C = 100, 130, 150, 170, 190 %, C/S = 30%, and L/C = 130% by weight. These ratios were selected after trial experiments. The diameter of specimens was kept constant as 100 and 150mm, and height to diameter (H/D) ratio is varied from 1 to 4. W/C is varied in order to study the failure mechanism of high strength and relatively weaker cement treated sand.

In order to investigate the internal behavior and strain distribution of cement treated sand, strain gauges were attached to a specially made silicone bars which are placed at the center of the specimens and were kept straight with the help of wires of strain gauges. Silicone has very less stiffness (Young's Modulus about 0.4 GPa) as compared with cement treated sands, so it has less effect on strain gauges attached to it (Fig. 2).

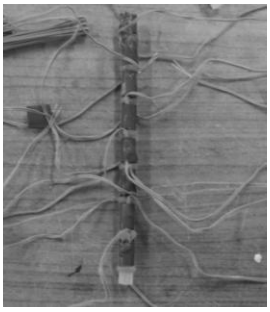


Fig. 2 Strain gauges attached to silicone bar

Unconfined compression tests were performed for curing period of 7 and 14 days. Curing is done by covering the specimens with wet clothes. Poorly graded sand (uniformly-graded) passing 5mm sieve was used having coefficient of uniformity and curvature about 2.2 and 1.0 respectively which was calculated according to Unified soil classification system [7]. The water absorption of sand was 1.32%. The density of sand, cement and limestone powder was 2.63, 2.70 and 3.16 g/cm^3 respectively, and density of specimen was about 2100 kg/m^3. Sand was first mixed with limestone powder and then with cement and finally water is added to the mix. Limestone powder was used to increase the viscosity of the paste and to make the mix more workable. The moisture which was already present in the limestone powder is ignored in the mix design.

Though, cement treated sand can bear compressive load but due to its plastic nature it undergoes volume change while performing compression test. Therefore, area correction was applied while calculating compressive strength of such cement treated sands. Corrected area, A is given as:

$$A = \frac{A_o}{1-\varepsilon} \tag{2}$$

A_o is initial average cross-sectional area, ε is average axial strain for given axial load (expressed as decimal) and it is calculated as:

$$\varepsilon = \frac{\Delta H}{H_o} \tag{3}$$

H_o is initial height of test specimen and ΔH is change in height of specimen.

Cyclic uniaxial compression test was performed by applying cyclic loads to the specimens in order to investigate the compression fracture zone and failure mechanism of cement treated sands. Splitting test on 150 x 150 mm specimens were carried out for different W/C ratios in accordance with ASTM [8].

100 x 100 x 400 mm beam specimens with central notch of 30mm were made to measure the tensile fracture energy (G_{ft}), and three point bending tests were carried [9] as shown in Fig. 3. The load was measured by using load cell and crack mouth opening displacement (CMOD) was measured with the help of two clip gauges attached to the specimen. The total number of specimens tested for determination of compressive strength, compression fracture zone length, notched beam test and splitting test were 144, 21, 25 and 10 respectively.

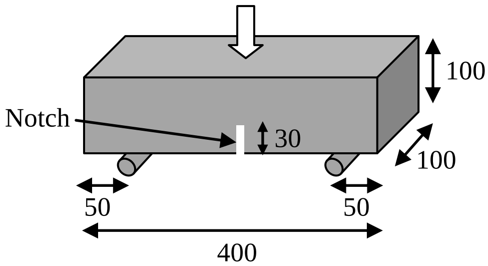


Fig. 3 Test specimen (mm) for G_{ft} determination

3. RESULTS AND DISCUSSIONS

3.1 Uniaxial Compression Test

Compressive strength for 14 days curing period of cement treated sand is summarized in Table 1. Development of strength with curing time for W/C ratio of 130 and 150% is shown in Fig. 4 and 5 respectively. It can be seen from the results that the compressive strength is independent of the size of the test specimens for cement treated sands.

Table 1: Compressive strength (MPa) of curing period of 14 days for different W/C ratios and diameter (a) 100mm (b) 150mm

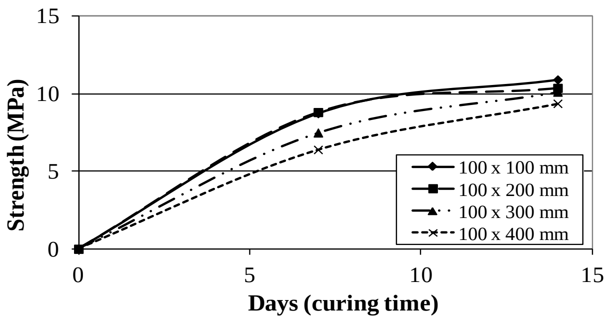
(a)

W/C (%)	**Specimen height (mm)**			
	100	**200**	**300**	**400**
100	21.15	20.14	18.89	17.98
130	10.92	10.37	10.13	9.38
150	7.22	6.65	6.96	6.06
170	4.76	4.81	4.36	4.12
190	3.19	3.47	3.76	3.71

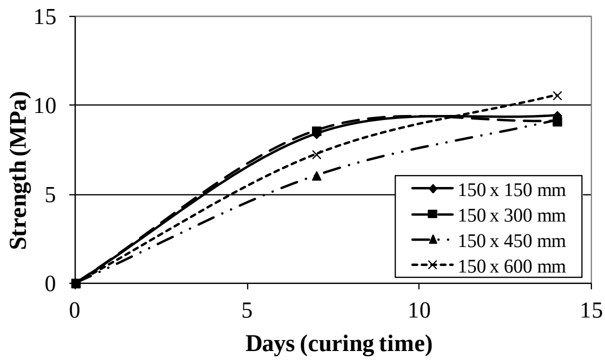
(b)

W/C (%)	**Specimen height (mm)**			
	150	**300**	**450**	**600**
100	18.40	18.76	-*	-*
130	9.45	9.12	9.19	10.59
150	5.76	6.18	5.18	5.28
170	4.10	3.71	3.56	3.42
190	3.10	3.26	-*	-*

-* specimen not casted

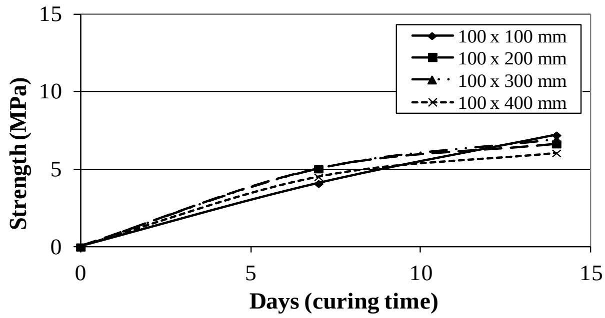


(a)

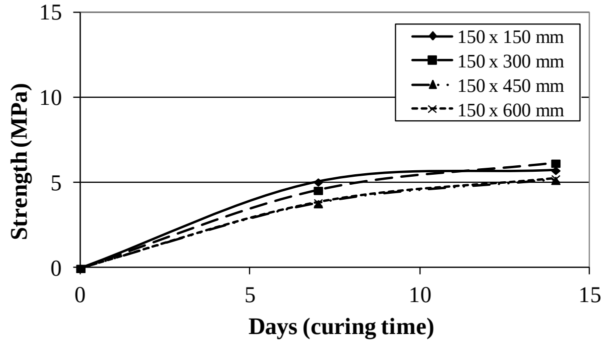


(b)

Fig. 4 Compressive strength for W/C = 130% of specimens having diameter (a) 100 mm (b) 150 mm



(a)



(b)

Fig. 5 Compressive strength for W/C = 150% of specimens having diameter (a) 100 mm (b) 150 mm

Strain corresponding to peak stress (14days) for such cement treated sands is about 0.003. Young's modulus (E) for 14 days curing period for specimen having 100 mm diameter using W/C = 100 % is about 6 GPa and was calculated according to ASTM [10] (Fig. 6). The behavior of cement treated sand was initially linear and then becomes nonlinear at high strain level.

$$E = \frac{S_2 - S_1}{\varepsilon_2 - 0.000050} \qquad (4)$$

where:

E = chord modulus of elasticity, psi
S_2 = stress corresponding to 40% of ultimate load
S_1 = stress corresponding to a longitudinal strain $\varepsilon_{1,}$ of 50 millionths, psi and
ε_2 = longitudinal strain produced by stress S_2.

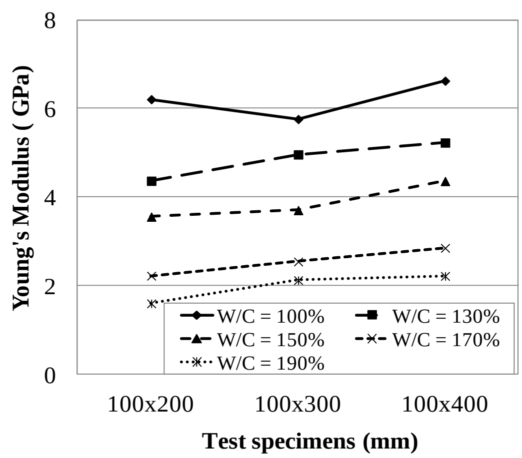
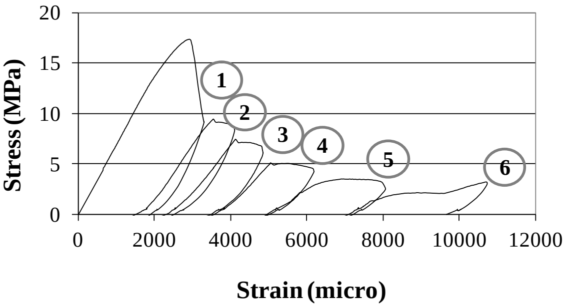


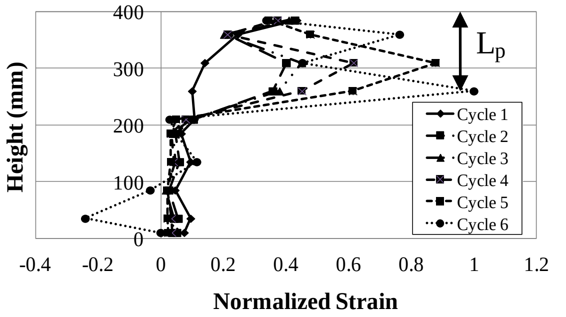
Fig. 6 Young's Modulus for different W/C ratios

3.2 Compression fracture zone length, L_p

Cyclic compression test is performed and results for 100 x 400 mm specimen having 100 mm diameter (W/C = 100%) is shown in Fig. 7a. Numbers in circle are indicating the loading cycle number. Strain distribution internally was measured by the strain gauges attached to silicone bar which was placed at the center of the test specimen and were attached to data logger for recording the strains (Fig. 7b).



(a)



(b)

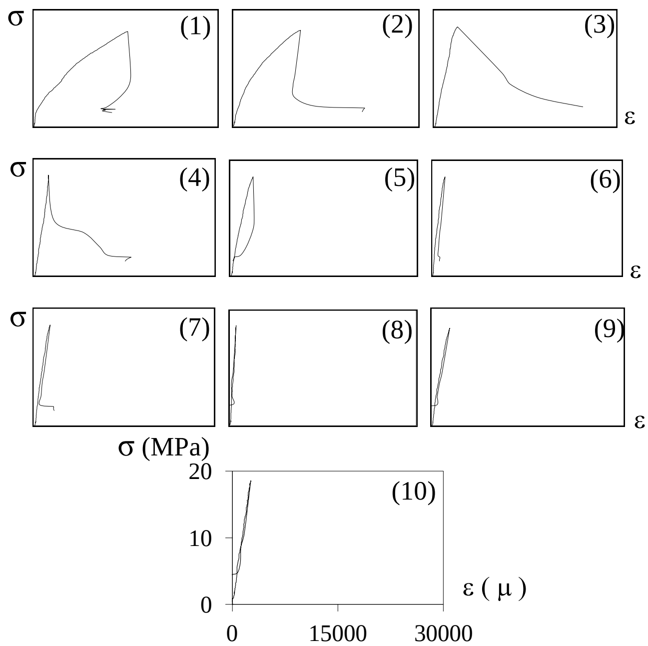
Fig. 7 (a) Uniaxial cyclic load test on a 100 x 400 mm specimen of W/C = 100% (b) Internal strain distribution of a 100 x 400 mm specimen

The techniques to measure the compression fracture zone length directly for concrete are suggested by Nakamura et al. [6] and later by Lertsrisakulrat et al. [11]. In this study the comparison of both techniques were carried out and suitable procedure for cement treated sand is suggested. According to Nakamura et al. [6] compression fracture zone length can be defined as the increasing zone of the local strain from the test results.

However, Lertsrisakulrat et al. [11], suggested determination of compression fracture zone length based on the quantification of energy absorbed throughout the specimen height and compressive fracture zone is defined as the zone in which the value of A_{inti} is larger than 15 percent of A_{int}. Where A_{inti} is the energy absorbed in each portion of the specimen and A_{int} is total energy absorbed throughout the specimen. Strain distribution for each loading cycle is shown in Fig. 7(b). Based on the concept of Nakamura et al. [6], compression fracture zone length of this specimen is about 200 mm as fracture zone can be identified from higher strain zone.

Local stress strain curve measured from inside the specimen for uniaxial cyclic test of W/C = 100% (100 x 400mm) specimen is shown in Fig. 8. It can be seen from local stress strain curve that some part shows increasing trend of strain (softening behavior) whereas some parts shows unloading behavior which distinguishes between fracture zone and unloading part. Fig. 8c shows the failed specimen. It can be seen from this figure that it is difficult to identify the fracture zone from outside of the specimen.

The method suggested by Lertsrisakulrat et al. [8], seems not feasible for cement treated sand or weaker material as the fracture zone may consist of small fracture energy. Fig. 9 shows energy consumed throughout the height of specimen 100 x 400 mm (W/C = 100%) calculated from local strain distribution. By using the method suggested by Lertsrisakulrat et al. [11], compression fracture zone length comes out to be about 155 mm which is smaller than the actual compression fracture zone length measures from the local strain distribution which is about 200 mm. However, if compressive fracture zone is defined as the zone in which the value of A_{inti} is larger than 5 percent of A_{int} then the fracture zone can be identified correctly.



(a) Local Stress Strain curve

(1)	385	(6)	185
(2)	360	(7)	135
(3)	310	(8)	85
(4)	260	(9)	35
(5)	210	(10)	10

(b) Stain gauge No. and located height (mm) (c) Failed specimen 100 x 400 (W/C = 100%)

Fig. 8 Distinction between failure and unloading

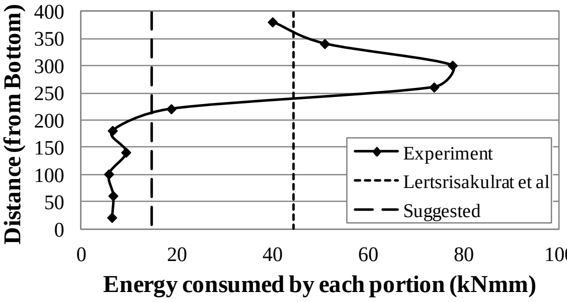
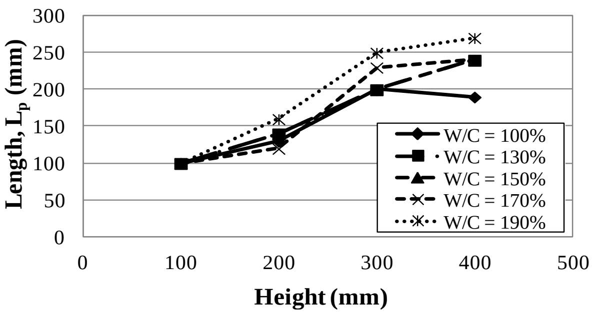


Fig. 9 Evaluation of Compression fracture zone length based on local energy concept

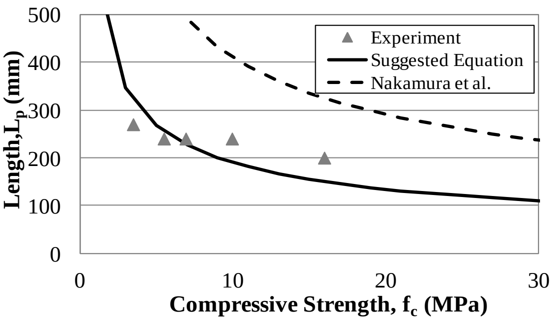
Effect on compression fracture zone length with different H/D ratio for 100 mm diameter specimen is shown in Fig. 10a. It can be seen that compression fracture zone length increases with the height until it reaches to a constant value of about 250 mm. Based on the test results (Fig. 10b) following equation is proposed for the estimation of compression fracture zone length (mm) from compressive strength (MPa) of cement treated sand:

$$L_p = \frac{600}{\sqrt{f_c}} \tag{5}$$

In conclusion of test results of different height specimens, it is found that strain localization only occurs in those specimens having height more than L_p.



(a)



(b)

Fig. 10 Compression fracture zone length variation with (a) height (b) compressive strength

3.3 Tensile fracture energy, G_{ft}

Cement treated sand are highly plastic which makes it possible to bear the uniaxial compressive load even after failure in tension. Specimen (150 x 150 mm) was first failed in tension by performing splitting test and then uniaxial compression test was performed on same specimen (Fig. 11). At splitting failure, the specimen not splits in half because of its plastic nature. The purpose of such tests was to get an idea that how cement treated sand will behave in compression after failure in tension. The difference in compressive strength of the specimen with and without prior failure in tension is about 10 %. This indicates that such cement treated sands are good in their application against cyclic loading as they can bear some load even after failure in tension. Variation of splitting tensile strength with compressive stress of cement treated sand is shown in Fig. 12.

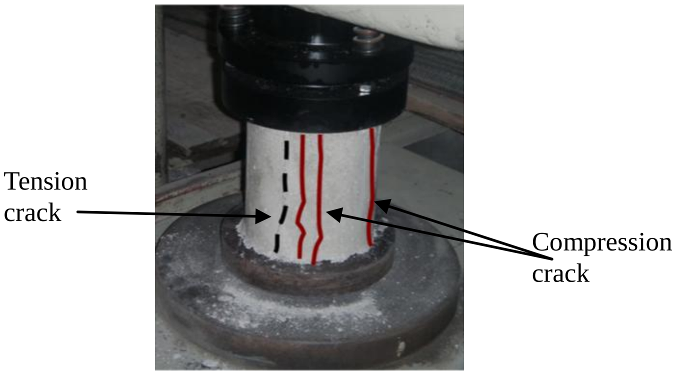


Fig. 11 Compression and tension test on same specimen

For concrete, splitting tensile strength can be estimated by using the equation proposed by Raphael et al. [12].

$$f_t = 0.3 f_c^{2/3} \tag{6}$$

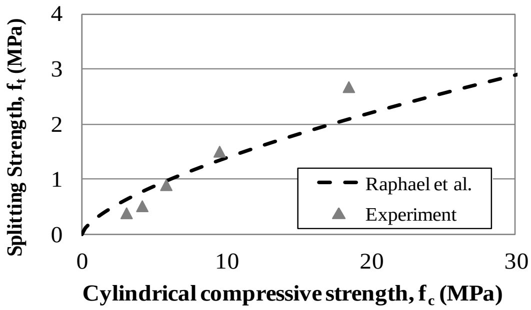


Fig. 12 Compressive strength ~ Splitting strength

The total amount of energy absorbed in tension test to failure is the tensile fracture energy, G_{ft}. Not only the tensile strength but the tensile behavior at fracture is very important. Three point bending tests were carried [9]. The load and CMOD curve is shown in Fig. 13 and effect of W/C ratio on tensile fracture energy of cement treated sand is shown in Fig. 14. Tensile energy computed from these tests can be used for modeling of cement treated sand in tension. The tensile fracture energy comes out to be very small even for high strength cement treated sand as compared with concrete because of absence of coarse aggregate.

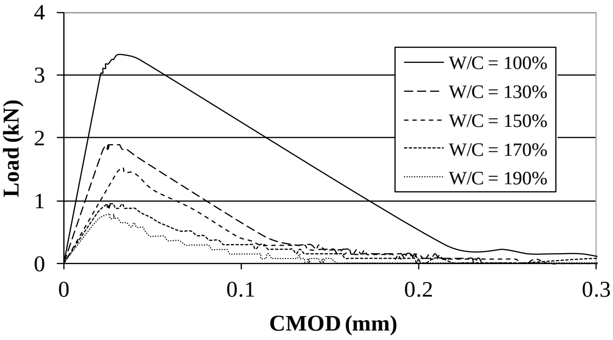


Fig. 13 Load CMOD curve for different W/C ratios

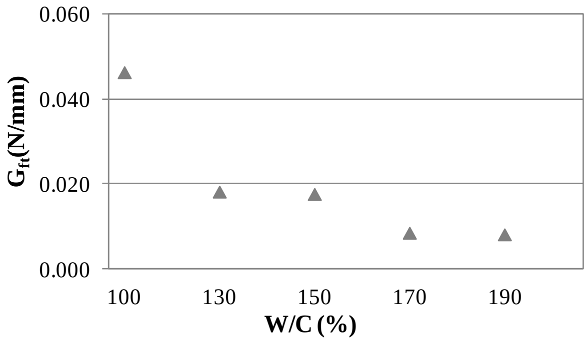


Fig. 14 Variation of tensile fracture energy with different W/C ratio

4. CONCLUSIONS

A series of uniaxial cyclic compression tests and notch beam tests were carried out in order to investigate the softening behavior of cement treated sand. Based on the test results, following are the conclusions:

(1) Maximum compressive stress of cement treated sand is independent of the size of the test specimen.
(2) Strain localization only occurs in those specimens having height more than L_p.
(3) The test results show that the compression fracture zone length increases with the height of the specimen and then it becomes constant to a height of about 250 mm.
(4) Tensile fracture energy of such cement treated sand is very small because of absence of coarse aggregates.
(5) Suggested relationship between compression fracture zone length and compressive stress will be helpful in analyzing the behavior of cement treated sands.

REFERENCES

[1] Lee, K. H. and Lee, S., "Mechanical properties of weakly bonded cement stabilized kaolin," KSCE Journal of Civil Engineering., Vol.6, No.4, 2002, pp. 389-398.
[2] Porbaha, A., Shibuya, S. and Kishida, T., "State of the art in deep soil mixing technology. Part III: geomaterial characterization," Journal of Ground Improvement, Vol.3, 2000, pp 91-110.
[3] Zhou, J., Qian, S., Beltran, S,G., Ye, G., Breugel, V,K. and Li, V., "Development of engineered cementitious composites with limestone powder and blast furnace slag," Material and Structures, 43, 2010, pp. 803-814.
[4] Nawa T, Izumi T. and Edamatsu Y., "State-of-the-art report on materials and design of self-compacting concrete," Proc. of the Int. Workshop on Self-Compacting Concrete, Kochi, Japan, 1998, pp 160–190.
[5] Markeset, G. and Hillerborg, A., "Softening of concrete in compression – localization and size effects," Cement and concrete research, Vol.25, No.4, 1995, pp 702-708.
[6] Nakamura, H. and Higai, T., "Compression fracture energy and fracture zone length of concrete," JCI-C51E Seminar on Post peak behavior of reinforced concrete structures subjected to seismic loads- Recent advances and challenges on analysis and design, Vol.2, 1999, pp 259-272.
[7] ASTM D2487, "Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)," 2006.
[8] ASTM C496/C496M, "Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens," 2004.
[9] JCI-S-001, "Method of test for fracture energy of concrete by use of notched beam," 2003.
[10] ASTM C469, "Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression," 2002.
[11] Lertsrisakulrat, T., Watanabe K., Matsuo, M., and Niwa, J., "Experimental study on parameters in localization of concrete subjected to compression," JSCE Journal of Materials, Concrete, Structures and Pavements, Vol.50, 2001, pp 309-321.
[12] Raphael, J. M., "Tensile Strength of Concrete," ACI Materials Journal, 81, No.2, 1984, pp. 158-65.