The Potential of Using Rubberchips as a Soft Clay Stabilizer Enhancing Agent

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Abstract

Soft clays generally display extremely low yield stresses, high compressibility, low strength, low permeability and consequently low quality for construction. Soil stabilization like soil-cement mixing can be effectively adopted to improve the strength and deformation characteristics of the soft clays. To incorporate a 'green' element in the existing stabilization technique, rubber chips derived from waste rubber tyres were used together with cement to stabilized kaolin in the laboratory, exploring the feasibility of the innovative stabilizer. A series of laboratory tests were carried out to study the fundamental mechanical and chemical properties of the cement-rubber chip stabilized kaolin. The mechanical properties examined included bender element and unconfined compressive strength, while the chemical properties included pH values, conductivity and the percentage of oxide concentration. The overall test results indicated that cement is effective in stabilizing the soils, where significant improvement of unconfined compressive strength (q_u) and P- and S- wave velocities (v_p and v_s) were observed. Increasing the percentage of rubber chips alone did not contribute much to strength improvement of the kaolin specimens but are able to increase the percentage of axial strain at failure compared to those specimens without rubber chips. Also, curing time was found to have a significant positive influence on q_u, v_p and v_s.

Keywords: Soft soil, Cement stabilization, Kaolin, Rubberchips, Bender element, Unconfined compressive strength

1. Introduction

In recent decades, the growth of automobile industry and the use of car as the main means of transport have increased greatly the number of tyres produced. This consequently generates a massive stockpile of used tyres. In the early 1990s, research projects were done to reuse tyres in different applications (Ganjian et al., 2008). The recent estimation of tyres stockpiled each year in different countries are as follows, i.e. United States - 300 million (Rubber Manufacturer's Association ,2000), England and Wales – 14 million (Hird et al., 2002), France - 10 million (Rubber Manufacturer's Association ,2000), Iran - 10 million (Ganjian et al., 2008), Turkey - 9 million (Unlu, H., 2006) and Malaysia - 1 million (Tung and Hasanan, 2007).

Since waste rubber is not easily biodegradable even after a long period of landfill treatment, material and energy recovery are alternatives to disposal (Segre and Joekes, 2000). On the other hand, a wide variety of waste materials have been suggested as additives to cement-based materials (Naik and Singh, 1991; Siddique and Naik, 2004). Innovative solutions to meet the challenge of tire disposal problem have long been in development. The promising options are: (1) use of tyre in asphaltic concrete mixtures; (2) incineration of tyres for the production of steam and (3) reuse of ground tyre rubber in a number of plastic and rubber products (Paul, 1985).

In Malaysia, for economic reasons, policies for the production of rubber are typically oriented towards benefiting the sizeable rubber industry, which has inadvertently resulted in a considerable problem of waste tires. As a counter-measure, the government is encouraging research on sustainable methods of handling the growing problem of rubber waste through various funds and grants.

Stabilization is a process of fundamentally changing the chemical properties of soft soils by adding binders or stabilizers, either in wet or dry conditions, to increase the strength and stiffness of the originally weak soils (Yilmaz and Degirmenci, 2009; Lee and Lee, 2002). Considering the possible negative environmental effects of chemical addition to soils, this study was conducted to explore the possibilities of using cement-rubberchips as a stabilizing agent. The combined admixture was intended to both reduce cost as well as to promote a more environmental-friendly and sustainable stabilizing agent. Kaolin was used as the base clay in the study to minimize variations due to properties of the soil sample itself.

2. Materials and Methodology

2.1 Kaolin

Kaolin served the purpose of artificial soft clay in this study, and was sourced from Kaolin Malaysia S/B. Physical and chemical properties of the kaolin sample are given in Tables 1 and 2.

2.2 Rubberchips (RC)

Rubber chips used in this study were retrieved from discarded used lorries tyre by crushing and removal of the textiles and metal fibers. The rubber chips size are between 2 to 5 mm in average. It was obtained from Yong Fong Rubber Industries Sdn. Bhd., Malaysia which produces reclaimed rubber such as rubber powder, rubber chips and rubber shreds.

2.3 Ordinary Portland Cement (OPC)

Ordinary Portland cement is widely used stabilizer, whether on its own or admixed with other additives. The cement was first oven-dried at 105˚ for 24 hours before being stored in airtight containers to maintain the consistency of cement used in the preparation of specimens. Chemical properties of OPC are given in Table 3 (Ho and Chan, 2009). The chemical composition of dry cement is: tricalcium silicates C_3S, dicalcium silicates C_2S, tricalcium aluminate C_3A and calcium ferroaluminate C_4AF, where C = CaO; S = SiO_2; A = Al_2O_3 and F = Fe_2O_3.

3. Experimental methods

3.1 Preparation of specimens

The test specimens were prepared by varying the portion of ordinary Portland cement and rubberchips added to kaolin paste of known water content (i.e. w = 50 %). Analysis was carried out for both mechanical and chemical properties by relating the effects of 0 - 4 % cement and 0 - 15 % rubberchips additions, as well as varying curing periods up to a month. These pre-determined percentages of additives were calculated based on dry weight of the kaolin.

The mixture was mixed thoroughly in a mechanical mixer and then compacted in a split mould to form specimens of 38 mm in diameter and 76 mm in height. A specially designed miniature hand compaction tool was used to compact the mixture in 4 layers, 50 blows each (Chan, 2006). The extruded specimens were then wrapped in cling films and stored for 28 days prior to testing. The specimens were prepared in pairs as an assurance of the repeatability of specimen preparation method and test procedures.

3.2 Bender element (BE) test

The bender element tests were conducted using the GDS Bender Element Test System. The test is essentially a nondestructively test for mechanical wave to test the integrity of concrete structures and to assess cement hydration (Fam and Santamarina, 1996). Evaluation of shear wave (v_s) and compression wave (v_p) velocities of geomaterials were applied in many geotechnical applications, both in the field and the laboratory (Ismail et al., 2005). These velocities can be used to calculate the small-strain shear modulus (G_o) and constrained modulus (M_o), respectively $G_o = v_s^2\rho$ and $Mo = v_p^2\rho$, where ρ is the bulk density of the tested material.

Changes in the pore fluid affect both double-layer repulsion and van der Walls attraction and therefore, influence shear wave velocity. While the use of P-wave to study cement hydration is not relevant during early stages of hydration since water is the stiffer component. P-waves can be used when the skeleton stiffness exceeds the stiffness of water (Fam and Santamarina, 1996).

The specimen was first placed on the base plate with the transmitting BE engaged in the slot at the bottom end, while the receiving BE was pushed into the slot at the top end of the specimen. As the test does not affect physically the specimens, measurements were carried out on the same specimens at the age of 0, 3, 7, 14 and 28 days. In this paper, the relationship between v_s and v_p to stiffness were studied.

3.3 Unconfined compressive strength (UCS) test

The unconfined compressive strength (UCS) test was conducted according to BS1377-7:1990 (British Standards Institution (BSI), 1990) with the Geocomp LoadTrac II triaxial test machine at a strain rate of 1.0 mm per minute. Care was taken to ensure that both ends of the specimen were as flat as possible to minimize bedding error during tests, especially with the stiffer specimens. The same specimens subjected to the BE test were tested at 28 days curing. The Young's modulus, E was determined from the stress-strain curve generated in the UCS test. The secantial Young's modulus, E_{sec} was derived by taking the gradient from the origin to the peak (i.e. q_u) of the plot.

3.4 pH values and conductivity

A portable pH/ EC meter (Hanna multi-parameter meter, HI 991300) was used to determine the pH values and conductivity of the soil specimen. A 10 g sample was weighed and diluted with 50 mL of deionized water. The pH values and conductivity of the solution were taken for each specimen.

3.5 X-ray fluorescence (XRF) analysis

The percentage of oxide concentration of the stabilized materials was examined using the X-Ray Fluorescence (XRF) analysis (XRF Bruker S4 Pioneer). A portion of soil was taken and put into the oven to be dried for 24 hours at 105 ºC. The dried sample was then grounded into fine particles passing the 0.063 mm sieve. However, rubber chips particles in the soil specimens were not able to be broken up or grounded into fine particles.

Hence, loose powder method of specimen preparation was adopted for such samples. The grounded sample was next transferred to a liquid sample holder (40 mm nominal diameter). This double open-ended sample holder enables pre-attachment of thin-film Mylar, which covers the bottom part of the sample holder. Samples were filled through the top opening of the sample holder. The lid of the liquid sample holder was covered with a full-size sleeve before running the test in the test chamber.

4. Results and Discussions

Each specimen was labelled using acronyms name, e.g. K0c5RC means kaolin (K) as soft clay, 0 % cement (0c) and 5 % rubberchips (5RC).

4.1 Elastic wave velocities

As shown in Figure 1, the velocities of P-wave (v_p) and S-wave (v_s) increased with the curing days and cement content. It was observed that the v_p and v_s increased over time and eventually reached a plateau after 7 days. This observation reflects the increased stiffness of the stabilized soil due to the hydration of cement with time, whereby it increased significantly in the first 7 days.

The effects of the amount of cement also increased the v_p and v_s, i.e. 2 % cement gave a lower curve line while 4 % cement gave a higher curve line despite the different amount of rubberchips.

A relationship can be established between v_p and v_s for the 28-day old specimen, i.e. $v_p = 0.9137v_s$ as shown in Figure 2. This relationship was observed that v_p is almost unity to v_s, whereby $v_p \approx v_s$. Also, correlation plots between UCS and the wave velocities are given in Figure 3. It can be concluded that basically cementation results in increased strength and stiffness. This phenomena shows that the cement-rubberchips stabilization starts with reduction of water content, then the improvement of physical properties, cement hydration hardening and lastly pozzolanic reaction hardening (in long term) (Kitazume, 2005).

4.2 Stress-strain relationship

Figure 4 shows the typical stress-strain curves of the cement-rubberchips stabilized specimens from the UCS tests. Specimens with 4 % cement displayed higher stiffness, as can be observed from the initial section of the curves, and also higher strengths. Looking at the specimens added with cement only, the 2 % and 4 % cement specimens appear to reach post peak strength immediately and then the curves dropped significantly. This behaviour of sudden rupture was very different from the result of (Chan and Ibrahim, 2009). As reported in (Chan and Ibrahim, 2009) which used 5 % and 10 % cement with the same amount of rubberchips. The result showed that the cement-rubberchips admixture was able to maintain certain strength post-yield (i.e. peak strength). It can be concluded that higher amount of cement content will give higher stiffness to the cement-rubberchips stabilized soil.

Rubberchips alone did not contribute much to strength improvement of the soft clay but are able to increase the failure strain compared to those specimen without rubberchips, i.e. specimens 0 % cement for 5RC, 10RC and

15RC is 11.212 %, 14.236 % and 10.387 % respectively. These specimens have an addition of 3 – 7 % more failure strain as compared to 2 % and 4 % cement (Figure 4). Therefore, this shows that the rubberchips only specimens will give lower peak strength and a progressive failure. Elasticity of the specimens is directly proportional to rubber content due to the elastic behavior of the rubber.

4.3 Unconfined compressive strength

The unconfined compressive strength (q_u) is plotted against the percentage of stabilizing agents in Figure 5. Note that the suffix indicates specimen 1 or 2 of the pair. The specimen pairs gave very similar results, pointing to the repeatability of the specimen preparation and the test method, as mentioned in section 3.1.

The original soil registered a low strength of $q_u \approx 77$ kPa. The cement-stabilised only specimens, i.e. K2c0RC-1 and K4c0RC-1, recorded q_u of 130 kPa and 249 kPa respectively, while K2c0RC-2 and K4c0RC-2, recorded q_u of 177 kPa and 311 kPa respectively. It can be seen that the K2c0RC strength is very similar to that of K2c5RC specimens, suggesting that the effect of 5 % rubberchips addition was negligible on strength improvement of the soil.

The cement-rubberchip stabilized specimens with 4 % cement achieved 2 times higher strengths than those with 2 % cement addition. This observation illustrates the dominant effect of cement as a combined stabilizer with rubberchips. Therefore, it can be concluded that strength increase due to cement-rubberchips is not apparent, when compared with the specimens stabilized with cement only.

Also, with 2 % cement addition, increased quantities of rubberchips did not contribute to significant strength increase, as can be seen in the drop in strength for specimens with 15 % rubberchips. The 4 % cement addition specimens, on the other hand, appeared to reach the highest strength with inclusion of only 5 % rubberchips, suggesting that there could be an optimum mix proportion for the cement-rubberchip admixture as seen in Figure 5, i.e. K4c10RC and K4c15RC dropped in qu.

4.4 Stiffness

Stiffness of the specimens was examined based on the secant Young's modulus (E_{sec}), taken from origin to the peak strength of a stress-strain plot. In Figure 6, E_{sec} is plotted with q_u for all the cement-rubberchips stabilized specimens. The linear correlation was found to yield $E_{sec} = 48.9\ q_u$, where higher strength specimens displayed higher stiffness too.

Figure 7 shows the relationship between Young's modulus for both shear modulus and constrained modulus. As mentioned in section 3.2, wave velocities were used to obtain the small-strain shear modulus (G_o) and constrained modulus (M_o). From this two relationships, a very obvious pattern can be seen, whereby when the cement content increased, E, G_o and M_o also increased. This was due to the changes in the pore fluid in the cement-rubberchips stabilized soil and therefore, influences the S-wave and G_o. Similarly, P-wave which influences the M_o also did increased because the skeleton stiffness of the stabilized soil was formed after 28 days curing. The cement content plays an important role in the increment of E, G_o and M_o, i.e. this relates well with the discussion in section 4.3.

4.5 pH values and conductivity

The pH affects the effectiveness of cement stabilization. The high pH value of samples containing hydrating cement may attributed to the dissociation of OH^- ions from the $Ca(OH)_2$ produced during hydration (Lee and Lee, 2002).

The pH values of stabilized soil were generally high (> 10). pH value for the original kaolin in this study is 4.55. It is obvious, as can be seen in Figure 8 that cement, and not rubberchips, contributed to the increment of pH value in the mixtures. This increase in pH is due to an increase in the electrolytic concentration of the pore water that results from dissociation of calcium hydroxide (Probaha et al., 2000).

Another significant observation was that the pH for 2 % cement with different RC (i.e. K2c0RC, K2c10RC and K2c15RC) and 4 % cement with different RC (i.e. K4c0RC, K4c10RC and K4c15RC) were very similar to one another, i.e. in a range of 11.53 – 11.81. It can be concluded that rubberchips compound could have leached out some chemical in the water in a very minimal range as seen when no cement was added into the soil. pH for K0c5RC, K0c10RC and K0c15RC were 5.22, 5.01 and 5.71 respectively. From Figure 8, it can also be observed that there was a drastic change in pH from cement content of 0 % to 2 %, after which the pH value appeared to be insensitive to the amount of cement added to the clay. The increase in pH values corresponds with the increased strength measured in the UCS tests (see Figures 5 and 6). pH must reach a minimum value of 9 to allow cementing reactions to occur (Tremblay et al., 1998). The long term pozzolanic reactions in the soil-cement were favored by high pH values, since the reactions are accelerated due to the solubility of the silicates and aluminates of the clay particles.

A hypothesis of clay cement interaction concluded that a primary and secondary process must be distinguished in the consolidation of the clay-cement mixture. The primary process includes hydrolysis and hydration of cement, in the course of which the usual hydration products appear and the pH value of the water increases. Hence, pH remained largely unchanged for cement content >2 % due to the hydration product from cement. The calcium hydroxide produced in this period and consumed during the course of secondary processes is partly replaced by the lime produced by the cement hydration (Lee and Lee, 2002).

As seen in Figure 9, the conductivity (in milli Siemens) is directly proportional to the different cement content. A linear relationship can be established where EC = 600c - 300. This is because electrical conductivity (EC) varies not only with the concentration of salts (natrium) present, but also the chemical composition of the soil solution (Resh, 2008). In other words, the higher the cement contents in a specimen, the higher the conductivity. Rubberchips do not contribute to the increment of EC, evident in the rubberchips added only specimens (Refer to plot 0 % cement).

It was also observed that conductivity increased with increased pH values (as shown in Figure 8, corresponding with the increase of oxide concentration in the specimens (Refer to oxide results in Table 4).

4.6 Oxide concentrations

Table 4 shows the major oxide concentrations of pure kaolin, cement, rubberchips and the stabilized samples with different rubberchips and cement content. Both SiO_2 and Al_2O_3 constituted the largest portions in all specimens. This is mainly due to the content of SiO_2 which can be found mainly from kaolin and cement hydration. In fact, SiO_2 forms the greatest portion in all the specimens, ranging from 50.06 % to 52.20 %.

In descending order, the portions of oxide go along trend of $SiO_2 > Al_2O_3 > CaO > Fe_2O_3 > SO_3 > ZnO$. Therefore, the implication of this concentration trend can determine the amount of oxide concentration that may leach out from the cement-rubberchips specimens from major to minor. Also, CaO increased when more cement was added (as mentioned in section 2.3). Kaolin, when mixed with cement, would be stabilized because cement and water react to form cementitious calcium silicate and aluminate hydrates, which bind the soil particles together. Hence, the hydration reaction releases calcium hydroxide, $Ca(OH)_2$ or slaked lime, which may in turn react with some components of the soil, in particular clay minerals (Bergado et al., 1996). This theory proved that both SiO_2 and Al_2O_3 constituted the largest portions in all specimens which mainly contributed by kaolin itself and cement.

The high pH (in Figure 8) accompanying cement hydration favours the solubility of SiO_2 and Al_2O_3, which interacts with the CaO from the hydrated cement and additional cementing material precipitate.

5. Conclusions

Following are the main conclusions drawn from this study:

- The velocities of P-waves (v_p) and S-waves (v_s) increased with curing period and cement content. A plateau was reached after 7 days indicating that the hydration of cement was fully completed in 7 days time causing the stabilized soil increased in stiffness. A relationship was established between v_p and v_s for specimens aged for 28 days, i.e. $v_p = 0.9137\ v_s$.
- Rubberchips alone did not contribute much to strength improvement of the kaolin specimens but are able to increase the percentage of axial strain compared to those specimen without rubberchips.
- At least 4% cement addition is required to achieve q_u = 250 kPa, while using only 5% rubberchips is sufficient and economical in the mix proportion for the cement-rubberchip admixture, i.e. K4c5RC can be a recommended mix.
- E_{sec} is approximately 49 times that of q_u for the kaolin stabilized with cement-rubberchip. While Young's modulus, $E_{sec} = 0.006\ G_o^{1.454}$ and $E_{sec} = 0.005\ M_o^{1.434}$ was found in this study.
- Both pH values and conductivity increased with cement content. Rubberchips is inert to the increment of conductivity.
- Relative values of oxide concentration for kaolin stabilized with cement-rubberchip: $SiO_2 > Al_2O_3 > CaO > Fe_2O_3 > SO_3 > ZnO$.

References

Bergado, D. T., Anderson, L. R., Miura, N. and Balasubramaniam, A. S. (1996). Soft ground improvement in lowland and other environments. New York: *ASCE Press*. 234-256

British Standards Institution (BSI). (1990). BS1377: British Standard Methods of Test for Soils for Civil Engineering Purposes. Part 7: Shear strength tests (total stress)

Chan, C.M. and Ibrahim, K.A. (2009). Ground improvement with cement-rubberchip stabilization. In Karstunen and Leoni (Eds.). *Geotechnics of Soft Soils - Focus on Ground Improvement*. Taylor & Francis Group, London, 207-211

Chan, C.M. (2006). A laboratory investigation of shear wave velocity in stabilized soft soils. PhD. thesis. University of Sheffield

Ch'ng, S.S. (2008). S-wave and unconfined compressive strength of cement-palf stabilized kaolin. B. Eng thesis. Universiti Tun Hussein Onn Malaysia

Fam, M.A. and Santamarina, J.C. (1996). Study of clay-cement slurries with mechanical and electromagnetic waves. *Journal of Geotechnical Engineering*, Vol. 122 (5) 365-372

Ganjian, E., Khorami, M. and Maghsoudi, A.A. (2008). Scrap-tyre-rubber replacement for aggregates and filler in concrete. *Construction and Building Materials*, 23, 1-9

Hird, A.B., Griffiths, P.J. and Smith, R.A. (2002). Tyre waste and resources management: A mass balance approach. Viridis Report VR2

Ho, M.H. and Chan, C.M. (2009). Chemical effects of cement-stabilised columns on the surrounding soils. *The 3rd International Geotechnical Symposium on Disaster Prevention and Reduction*, IGS2009. 22-24 July 2009, Harbin, China. 326-333

Ismail, M.A., Sharma, S.S. and Fahey, M. (2005). A small true triaxial apparatus with wave velocity measurement. *Geotechnical Testing Journal*, Vol. 28 (2) 1-10

Kaolin (M) Sdn Bhd. (2008). [Online] Available: http://www.kaolin.com.my/product.html (26 March 2008)

Kitazume, M. (2005). State of Practice Report: Field and laboratory investigation, properties of binders and stabilised soils. *Proceeding of the International Conference on Deep Mixing Best Practice and Recent Advances, Stockholm*, Sweden, Vol. 2, 660-684

Lee, K.H. and Lee, S. (2002). Mechanical properties of weakly bonded cement stabilized kaolin. *KSCE Journal of Civil Engineering*, Vol. 6 (4) 389-398

Naik, T.R. and Singh, S.S. (1991). Utilization of discarded tires as construction materials for transportation facilities. Report No. CBU-1991-02, UWM Center for By-products Utilization, 16

Paul, J. (1985). Encyclopedia of Polymer Science and Engineering 14, 787-802

Probaha, A., Shibuya, S. and Kishida, T. (2000). State of the art in deep mixing technology. Part III: Geomaterials Characterization. *Ground Improvement*, Vol. 3, 91-110

Resh, H.M. (2008). Hydroponics food production. PhD. [Online] Available: http://www.kaolin.com.my/product.html (26 March 2008)

Rubber Manufacturer's Association (2000). Washington, DC.

Segre, N. and Joekes, I. (2000). Use of tire rubber particles as addition to cement paste. *Cement and Concrete Research*, 30, 1421-1425

Siddique, R. and Naik, T.R. (2004). Properties of concrete containing scrap-tire rubber – an overview. *Waste Management*, 24, 563-569

Tremblay, H., Leroueil, S. and Locat, J. (1998). Stabilization of clayey soils from Eastern Canada at high water contents. *Proceedings of the 3rd International Congress on Environmental Geotechnics*, Lisbon, Portugal. 337-340

Tung, C.L. and Hasanan, M.N. (2007) Effect of curing conditions on the compressive strength of crumb rubber concrete paving blocks. *World Engineering Congress*, Penang, Malaysia, 335-340

Unlu, H. (2006). Recovery of hazardous wastes in automobile industry. Master Thesis: Natural Science Institute of Uludag University, Turkey

Yilmaz, A. and Degirmenci, N. (2009). Possibility of using waste tire rubber and fly ash with Portland cement as construction materials. *Waste Management*, 29 (5) 1541-1546

Table 1. Kaolin physical properties (Kaolin (M) Sdn Bhd., 2008)

Properties	Kaolin
Moisture Content	< 7 %
pH (30% solution)	3.5 – 6.0
Brightness	75 % – 82 %
Average Particle Size	3.0 – 5.5 μm
Specific gravity	2.6
Liquid limit (%)	60.5*
Plastic limit (%)	42.5*
Plasticity index (%)	18*

*conducted by Ch'ng, (2008)

Table 2. Kaolin chemical composition by XRF test

Formula	Concentration (%)
SiO_2	54.7
Al_2O_3	41.2
K_2O	1.83
Fe_2O_3	0.93
TiO_2	0.66

Table 3. Chemical properties of ordinary Portland cement by XRF test

Chemical Composition	Content (%)
Silica (SiO_2)	18.30
Alumina (Al_2O_3)	4.68
Iron Oxide (Fe_2O_3)	2.32
Calcium Oxide (CaO)	66.80
Magnesium Oxide (MgO)	1.59
Sodium Oxide (Na_2O)	0.28
Potassium Oxide (K_2O)	0.57
Sulphur Trioxide (SO_3)	5.03
Titanium Oxide (TiO_2)	0.21

Table 4. Major oxide concentration of the specimens

Oxide Concentration	Kaolin	Cement	Rubber Chips	2c			4c		
				5RC	10RC	15RC	5RC	10RC	15RC
Al_2O_3	41.83	4.68	16.20	40.94	41.04	39.76	40.57	39.20	39.19
CaO	0.21	66.80	44.87	1.87	2.02	1.97	3.23	3.24	3.31
Fe_2O_3	1.65	2.32	1.28	1.68	1.68	1.73	1.74	1.73	1.74
SiO_2	51.91	18.30	20.50	51.06	50.83	52.20	50.06	51.24	51.05
SO_3	0.13	5.03	6.89	0.29	0.20	0.21	0.26	0.26	0.29
ZnO	-	-	6.96	0.03	0.12	0.07	0.05	0.04	0.19

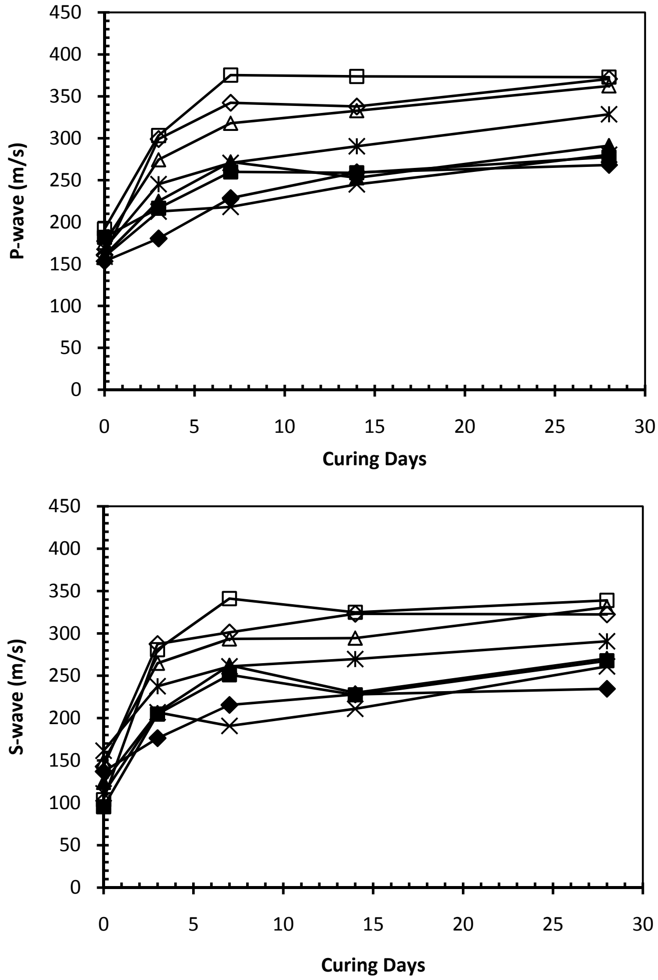

Figure 1. P-wave and S-wave - Curing Days

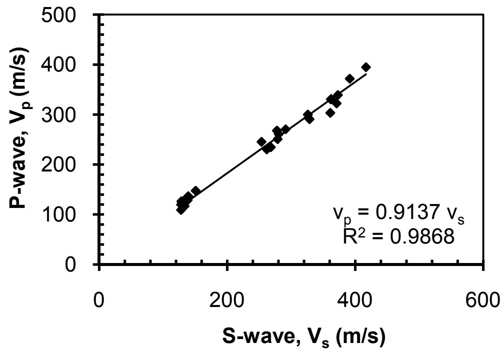

Figure 2. Correlation between v_p and v_s

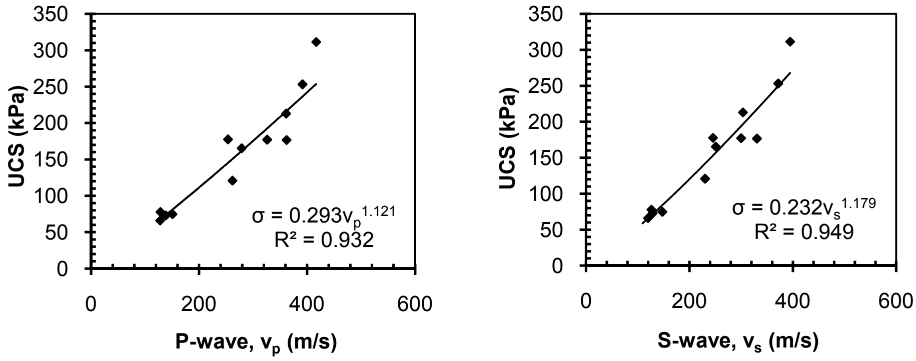

Figure 3. Relatioship between UCS and Wave Velocities

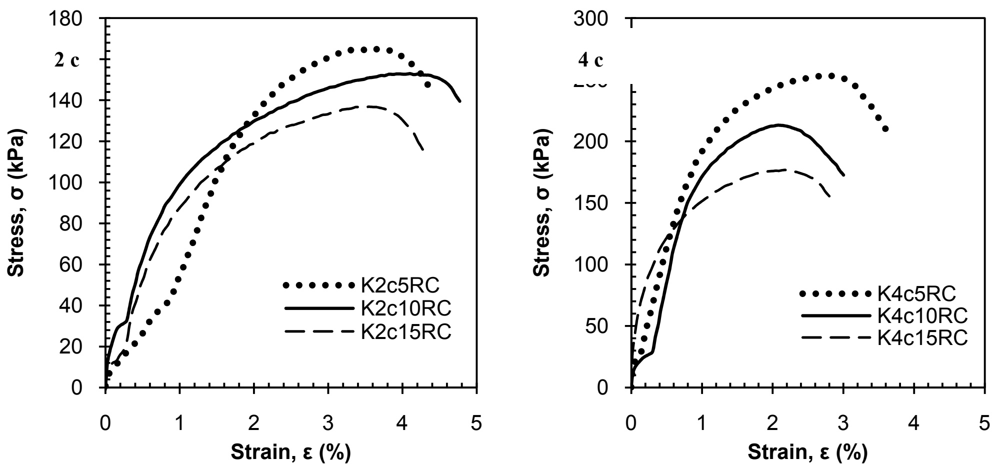

Figure 4. Stress-strain Curves for 2 % and 4 % Cement

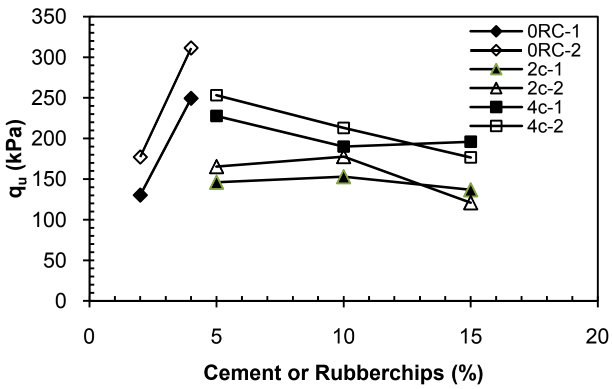

Figure 5. q_u – Cement or Rubberchips

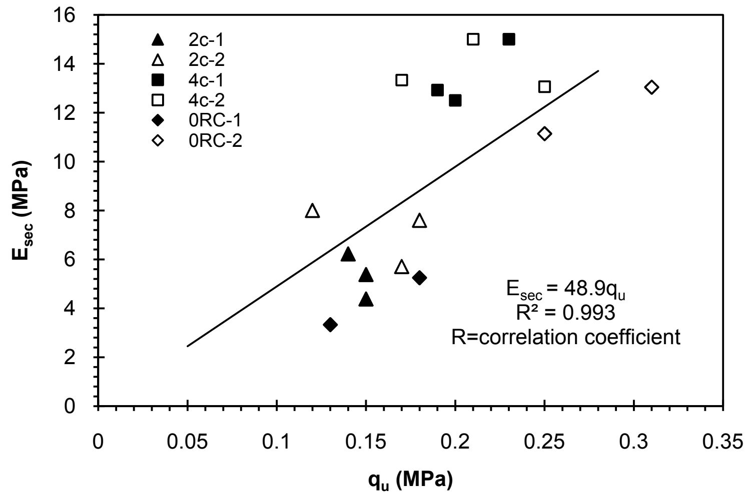

Figure 6. E_{sec} - q_u

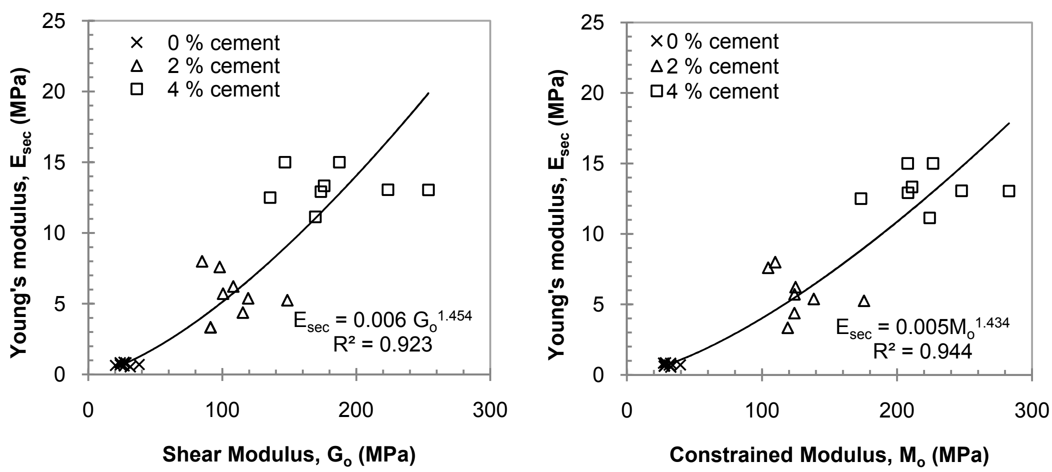

Figure 7. E_{sec} – G_o and M_o