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Long-Term Durability of Ordinary Portland Cement and Polypropylene Fiber Stabilized Soil

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LONG-TERM DURABILITY OF ORDINARY PORTLAND CEMENT AND POLYPROPYLENE FIBER STABILIZED CLAY

by

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TITLE: LONG-TERM DURABILITY OF ORDINARY PORTLAND CEMENT AND POLYPROPYLENE FIBER STABILIZED CLAY

MAJOR PROFESSOR: Dr. Prabir K. Kolay

Soft soil stabilization frequently uses cement, lime, fly ash, etc., but very limited studies were conducted on the long-term durability of stabilized soil. The present research work deals with the long-term durability of commercially available soil (i.e., EPK clay) stabilized with ordinary Portland cement and polypropylene fiber using a realistic approach, where the effect can be noticed in each weathering cycle. In the present study, two different tests (i.e., wetting-drying and freezing-thawing) were conducted to analyze the long-term durability of stabilized soil. Cycles of higher temperature followed by rainfall, which generally occurs in southern states of the US, were analyzed by the wetting-drying test; and on the other hand, cycles of freezing temperature followed by normal temperature, which generally occurs in northern states of the US and Canada, were analyzed by the freezing-thawing test. For the mid-continental region where freezing, normal, and higher temperature followed by rainfall are expected to occur, hence both the test method i.e., wetting-drying and freezing-thawing, were suggested. Laboratory experimental investigations were conducted to find the percentage loss of stabilized soil during wetting-drying and freezing-thawing tests, which were used as a durability indicator for cement and cement-fiber stabilized soil. Stabilized samples were subjected to harsh environmental conditions in a laboratory set up, and their deterioration was observed and studied after each wetting-drying and freezing-thawing cycle. In the real world, stabilized soil encounters seasonal cycles of monsoon and summer in long run of its service life which was simulated in rapid weathering cycles in laboratory setup. EPK clay samples were stabilized with different percentages of cement, and a mix of cement-fiber combination and were subjected to 12 cycles of wetting-drying and freezing-thawing cycles separately to determine the percentage loss of soil in accordance with the ASTM standards. Finally, based on percentage loss of soil of those stabilized samples which survived up to 12 cycles of weathering action, the optimum content of stabilizing agent was determined for wetting-drying and freezing-thawing tests. Results of wetting-drying tests indicate that EPK clay stabilized with ordinary Portland cement and fiber combination survived up to 12 cycles, but only 10% cement + 0.5% fiber was durable against wetting-drying based on percentage loss. For all the samples stabilized with 10% cement + 0.5% fiber combination, the percentage loss of soil when subjected to durability test was less than 7%, which satisfy the Portland Cement Association's (PCAs) durability specification. The results of freezing-thawing tests indicate that the EPK clay stabilized with 10% cement, 5% cement + 0.5% fiber, and 10% cement + 0.5% fiber survived up to 12 cycles and were durable against freezing-thawing based on percentage loss of soil i.e., less than 7% which satisfy the Portland Cement Association's durability specification.

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CHAPTER 1

INTRODUCTION

1.1 Background

The concept of soil stabilization has been established since long before when the shortage of aggregate and resource compelled people to think of an alternative way to stabilize the poor construction site. History begins with the chemical stabilization of soil when Mesopotamians and Romans improved the load carrying capacity of pathways by mixing the underneath soil with pulverized limestone (Ellaby, 2010). In the modern era, as the demand for soil stabilization increases, different techniques have been invented. Mechanical, hydraulic, chemical and reinforcement inclusion are some common methods that are widely used throughout the modern era for soil stabilization. Chemical stabilization is one of the major and most important methods of soil stabilization. This method can be used along with mechanical, inclusion or hydraulic methods to provide better performance. In chemical soil stabilization methods, soil is mixed with chemicals to alter their properties. Various chemicals like cement, lime, fly ash, bitumen, tar, by-products, chemical waste or sludge, and blends of these chemicals are used for soil stabilization. Chemicals like aluminum and silicon are used as a filler product to reduce the voids. Silicate-aluminates amide is used for strength improvement and water cutoff. Potassium based chemical stabilizer is effective in controlling the swelling potential of expansive soil. Similarly, sodium hydroxide improves the strength, optimum moisture content (OMC) and maximum dry density (MDD) (Kazemian et al., 2010). The major advantage of chemical soil stabilization is that setting time and curing time of chemically stabilized soil can be controlled easily. Also, chemical stabilization gives more strength and decreases permeability. Because of this significant advantages, most of the soil stabilization is performed by using chemicals, and thus, chemical stabilization is also termed as soil stabilization (Kazemian et al., 2010; Zhao et al., 2014; Abid, 2016; Firoozi et al., 2017). Even during the Vietnam war, US military had used cement, and lime to improve the strength of poor soil and support the heavy aircraft traffic (Ellaby, 2010).

Performance measurement of stabilized soil is one of the important aspects. This is normally addressed as a durability test of stabilized soil. Stabilized soil undergoes various deteriorating factors and weathering phenomenon. Sometimes stabilized soil even may encounter flood and drought cycles. Extreme high temperature and rainfall could be another weathering phenomenon. Normally, southern states of the US like Texas, Louisiana, Florida face this phenomenon. Similarly, stabilized soil may encounter cycles of freezing temperature and normal temperature, which is a deteriorating factor. Normally, the northern part of the US like Wyoming, Dakota, Idaho encounter this situation. The temperature of Chicago reached up to 105° F in 2012 and -23° F in 2019. Based on 1971 to 2000 climate data (rssweather.com), January's average temperature of Chicago, IL was 14.3°F and July's average temperature was 83.5°F. Similarly, the average temperature of Williston, North Dakota in January was -3.3°F and in July was 83.4°F. The average temperature of Houston, Texas in the month of January was 41.2°F and July was 93.6°F. Average precipitation of Houston in June was 5.35 inches. From this data, it can be observed that cycles of lower temperature and higher temperature followed by rainfall occur in real world phenomena. Similar weathering phenomenon can be expected multiple times in the long run of stabilized soil. In general, every part of the United States encounters seasonal cycles of higher temperature and rainfall during summer and cycles of freezing temperature and normal temperature during winter, which can be simulated as deteriorating factors. Durability mainly depends on the type of chemical stabilizer, the quantity of stabilizer, nature of weathering phenomenon and number of deteriorating cycles. To represent the different environmental conditions, stabilized soil is also subjected to different harsh condition during the test. Finally, durability is measured based on dielectric value, pulse velocity, percentage loss of soil mass, and unconfined compressive strength before and after the weathering cycles.

1.2 Scope

The present study investigates the long-term durability of EPK clay stabilized with ordinary Portland cement, and polypropylene fiber. EPK clay was stabilized with 5% and 10% ordinary Portland cement by dry weight of clay in combination with 0.5% polypropylene fiber. In total, five different combinations of EPK clay were subjected to two different durability tests. Three replicated Proctor samples were prepared at OMC (Optimum Moisture Content) for each combination resulting in a total of 30 samples. Commercially available EPK clay, ordinary Portland cement, and 0.25 inch (6 mm) long polypropylene fiber were used in this study. Physical properties of EPK clay was determined by specific gravity test, hydrometer test, Atterberg limit test, and miniature Proctor compaction test. Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for each combination were determined. X-Ray diffraction (XRD) was carried out for original EPK clay, and EPK clay mixed with 5% and 10% ordinary Portland cement. Also, Scanning Electron Microscope (SEM) and Energy Dispersive X-Ray Analysis (EDAX) were conducted for original EPK clay, and EPK clay mixed with 5% and 10% ordinary Portland cement. Wetting-Drying and Freezing-Thawing were two different tests used for the evaluation of the durability of stabilized soil. For both tests, 12 cycles of weathering action were simulated under laboratory control setup. After the durability test, a compressive strength test was carried out on survived samples.

1.3 Thesis Organization

The present work is organized into five different chapters.

Chapter 1 briefly describes the background of soil stabilization, need for soil stabilization and durability test. This chapter also includes the scope of this research work and organization of work.

Chapter 2 presents the past work conducted to stabilize the soil using different types of chemical or stabilizer. Mainly, this chapters presents the literature review of different type of durability test.

Chapter 3 discuss different types of material used for research purpose and their characterization along with the testing procedure used for durability test. This chapter also contains the various durability criteria used to analyze the result of the durability test.

Chapter 4 presents the results of soil characterization, XRD test, SEM/EDAX test, Wetting-Drying test, Freezing-Thawing test, and the discussion of result.

Chapter 5 discuss about the conclusion of this research, summarized the finding and propose the recommendation for future work of the durability test.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Many studies were conducted about the durability of different types of stabilized soil and various methods of durability measurement are in practice. Some studies compared between the different types of durability measurement which are in practice. The type of method depends on the importance of projects, time, resource and economic conditions. "ASTM D4609 Standard Guide for Evaluating Effectiveness of Chemicals for Soil Stabilization" suggests the durability of stabilized soil based on Unconfined Compressive Strength (UCS). ASTM D 4609 recommends that an increase in UCS of 50 psi or more, measured after 7 days of curing due to chemical treatment to be considered effective as a stabilizing agent. However, wetting-drying and freezing-thawing are most realistic but are time-consuming methods. Freeze-thaw tests should be conducted in areas that are subject to freezing conditions, such as cold regions, while wetting-drying cycles should be conducted in all geographic areas (Zhang & Tao, 2006). When pores filled with water in stabilized soil formed ice during freezing, the volume increased and resulted in microcracks due to tensile stress around soil particles (Shang et al., 2008). Different terms and parameters were established by various authors to represent the durability test result. Kamei et al. (2013) represent the durability test results in terms of *durability index* which is defined as the ratio of ultimate compressive strength of specimen after the desired number of weathering cycles to the ultimate compressive strength of an identical specimen subjected to only 28 days curing without weathering effect. Many studies were conducted on the durability test of soil stabilized with various combinations of cement, lime, fly ash, recycled waste, fiber, bitumen, rice husk, and gypsum.

2.2 Effect of chemical stabilization on compaction of soil

Gupta and Kumar (2016) suggested that the maximum dry density (MDD) of cement stabilized soil slightly decreases from 1.78 to 1.64 gm/cc and optimum moisture content (OMC) increases slightly. Also, the effect of cement and fiber along with the curing period significantly increases the properties of cement stabilized and fiber reinforced clay-pond ash mixes. Cement decreases the maximum dry density and increases the optimum moisture content slightly. From the plasticity viewpoint, 6-8% of cement is economical and recommended for soil stabilization (Basha et al., 2005). Muhunthan and Sariosseiri (2008) studied the change in Atterberg limit of stabilized soil using different cement content as a stabilizing agent, and the authors suggested that liquid limit increases initially and decreases with the addition of cement content, while plastic limit remains constant. So, plasticity index increases initially with the increase of cement content and then decreases on further increase in cement content. Percent of cement content depends on the type of soil. Increase in cement content increases the OMC. With the increase in OMC, MDD initially decreases and then increases with further increase in cement content. Muhunthan and Sariosseiri (2008) also suggested that cement-treated soil possess more brittleness compared to non-treated samples. Due to the effect of freezing-thawing cycles, void ratio increases for the dense soil and decreases for the loose soil, whereas hydraulic permeability increases due to developed cracks and void when ice thaws (Vermeer et al., 2006).

2.3 Durability test of stabilized soil

2.3.1 Lime Treated Soil

Dempsey and Thompson (1968), Kelley (1977), Little (1998), Khattab et al. (2007), Yilmaz et al. (2015) studied the effect of lime on long-term performance of stabilized soil. Lime treatment for the stabilization of soil has been used since long ago to improve the strength and durability of stabilized soil and decrease the swelling potential of expansive soil (Metcalf, 1977; Little, 1995; Bell, 1996; Little, 1996; Khattab et al., 2000; Lopez Lara & Castano, 2001). Very limited studies were conducted in the long-term durability of stabilized soil subjected to deterioration due to environmental factors such as wetting-drying and freezing-thawing cycles on engineering properties of soils (Khattab et al., 2007). Little (1998) suggested that soil stabilized with lime increases the structural properties of soil based on dielectric value and Unconfined Compressive Strength (UCS). Little (1998) suggests that for lime treated soil, resilient properties increase significantly compared over untreated soil. Dempsey et al. (1968) evaluated the durability properties of lime treated four Illinois representative soils. Volume change and strength loss due to freezing-thawing were evaluated and found that average loss of strength for lime treated soil with 48 hours curing is 60 kPa per cycle. Yildiz and Soganci (2012) studied the effect of freezing-thawing on permeability and strength of lime treated soil. Two types of soil, high plasticity clay and low plasticity clay, were treated with 6% lime. Yildiz and Soganci (2012) conducted the permeability test after three freezing-thawing cycles and result showed that the increase of hydraulic conductivity due to the freezing-thawing cycle. After the lime stabilization, unconfined compressive strength of high plasticity clay increased by 15 times, while the unconfined compressive strength of low plasticity clay increased by just three times. Thus, lime stabilization is more suitable for high plasticity clay rather than on low plasticity clay (Yildiz & Soganci, 2012). The addition of lime reduces the plasticity index of high plastic soil. When lime treated soil is long term exposed to water, detrimental effects of exposed conditions are not significant, and the ratio of weathered to unexposed unconfined compressive strength is high, approximately 0.7 to 0.85 (Thompson, 1970; Little, 1998; Dumbleton, 1962). This confirms the durability of lime treated soil. Yilmaz et al. (2015) studied the clay soil stabilization using Green Bayburt Stone (GBS) and lime subjected to freezing-thawing cycles. GBS is a waste material consisting of 68% SiO_2 and have pozzolanic property. Yilmaz et al. (2015) found that with the addition of GBS without lime does not have significant change in strength before subjecting to freezing-thawing, but with the addition of 6% lime in various content of GBS, compressive strength increases more than 1000%. Also, strength of soil stabilized with GBS and lime subjected to freezing-thawing was not decreased significantly due to the effect of freezing-thawing with respect to natural properties of soil. Yilmaz et al. (2015) conclude that GBS along with lime can be used for soil stabilization. Khattab et al. (2007) studied the long-term stability of lime treated bentonite soil. Wetting-drying and freezing-thawing both weathering actions were subjected to evaluate the long-term characteristics. Before applying wetting-drying action, Khattab et al. (2007) predried the soil sample at 60^{o}C to represent the environmental effect of an arid region on swelling and strength behavior. Khattab et al. (2007) found that 4% lime is optimum for the stability of bentonite soil; further addition of lime reduces the swelling potential. The effect of predried was significantly seen on initial shrinkage. Lime treatment induces the change in pore size distribution, pore volume increases, resulting in an increase in permeability of clay soil. Khattab et al. (2007) also investigate that lime stabilized soil should not be exposed to drying too early after the curing. Lime treated soil should be protected from heat and direct sunlight during hot seasons to have a maximum efficiency of lime treatment. Puppala and Pedarla (2017) research results suggested that, for both shallow and deep expansive soil in Texas, 8% lime treated soil gave the better performance based on the vertical movement of stabilized soil.

2.3.2 Cement Treated Soil

A lot of research and studies were conducted on the performance of soil stabilized with cement as a stabilizer agent. Ahmed and Ugai (2011), Shihata and Baghdadi (2001), Kamei et al. (2013), Zhang and Tao (2008), Kelley (1977) suggested cement as good stabilizing chemicals for soil. Zaman et al. (1992) investigated the effect of wetting-drying and freezing-thawing cycle for the durability cement kiln dust stabilized samples and found that significant decrease in strength due to wetting-drying and freezing-cycles. Shihata and Baghdadi (2001) studied the long-term strength and durability of soil containing high sulfate. Sulfate resistant Portland cement was used as stabilizing chemical and durability was evaluated based on wetting-drying and freezing-thawing weathering action. To study the effect of long-term exposure on the wetting-drying durability, specimens were immersed in saline water for different duration 7, 90, 180, 270 and 360 days before running 12 wetting-drying cycles. For long term durability against freezing-thawing, immersion period was 7, 270, and 360 days. Immersion period before wetting-drying and freezing-thawing cycles were referred as "*Exposure Period*". Shihata and Baghdadi (2001) found that if the amount of finer particles (passing through 200 mm sieve) is greater, it exhibits higher mass loss percentage in wetting-drying test whereas coarse gradation soil (smaller amount of fines) has higher mass loss percentage in the freezing-thawing test. In wetting-drying cycle, residual strength increases with the increase in exposure period up to 90 days exposure period, after which it decreases rapidly for up to 270 days exposure. But in freezing-thawing test, with the increase in weathering cycle, residual strength tends to decrease continuously from the beginning. The strength of 270 days considered as long-term strength and unbrushed residual strength was higher than brushed residual strength. In freezing-thawing action, there was a larger drop in long-term residual strength and the ratio of long-term strength (at 270 days exposure) to the residual strength at 7 days was smaller in freezing-thawing test than in wetting-drying test. Research showed that there is a good correlation between residual strength obtained from two different durability test (R^2 = 0.884). Zhang and Tao (2008) studied the durability of cement stabilized low plasticity soils using various percentage of Type I Portland cement (2.5, 4.5, 6.5, 8.5, 10.5, and 12.5%). Zhang and Tao (2008) compared the durability of wetting-drying action with durability measurement by tube suction test method. Sample with molding moisture content of OMC or on wet side took longer time to reach maximum dielectric value than those molded on dry side. Maximum dielectric value decreases with increasing cement content and with increase in moisture content dielectric value increases. In the Unconfined Compressive Strength (UCS) test of Tube Suction (TS) sample, UCS increase with increase in cement content at lower moisture content. There is correlation between the UCS of TS sample and dielectric value. UCS of TS sample generally decreased with increase in maximum dielectric value. Due to long-term hydration during wetting-drying cycle, strength of cementitious materials increases (Toutanji et al., 2004; Rahman, 2007; Yaykiran, 2008).

2.3.3 Cement, Lime and Gypsum treated soil

Ahmed and Ugai (2011) have evaluated the effect of wetting-drying and freezing-thawing on sandy soil, and sand silt stabilized with recycled gypsum and cement. Recycled gypsum content of 0, 5, 10, and 20% and cement of 0, 1.25, 2.5, and 5% by weight of soil were used for the research purpose. Ahmed and Ugai (2011) studied the effect of chemical stabilization on compressive strength, soil-gypsum cement loss and volume change. The compressive strength increases with the increase of the recycled gypsum content because of cementation or hardening of soil particle. Cohesion strength developed between particle and addition of cement improves the performance of soil-gypsum, whereas strength decreased with increase in number of wetting-drying and freezing-thawing cycles. Specimen stabilized with only gypsum without solidification agent, cement, is not durable against freeze-thaw and wet-dry action for compressive strength test due to solubility of gypsum. Addition of cement decreases the weathering effect on behavior of strength. In soil-gypsum cement loss test, most of the specimen stabilized with only gypsum without cement content, collapsed after first weathering cycle except the one with 20% gypsum which collapses after fourth cycles and trend of weight loss is same for both wetting-drying and freezing-thawing process. With increase in cement content, soil loss weight decreases. Ahmed and Ugai (2011) suggested that more than 2.5% of cement is adequate to resist effect of wetting-drying and freezing-thawing weathering cycle on soil that is stabilized with gypsum. Soil-gypsum-cement has good durability for volumetric change. Further, Kamei et al. (2013) studied the durability of very soft clay stabilized with recycled basanite and furnace cement mixture. Basanite and gypsum both have same mineralogical composition- calcium sulfate. Type B furnace slag cement of 5 and 10% along with recycled basanite soil ratio (B/S) of 0, 10, 20 and 40 were used to investigate the durability of stabilized kaolin clay (65% clay and 35% silt). Kamei et. al. (2013) evaluate the durability by measuring UCS, durability index and volume change of sample subjected to wetting-drying weathering action. JHS 2001 specification was used for wetting-drying test. Research found that with increase in basanite content, UCS increases and strength decrease with increase in wetting-drying cycles. Wetting-drying cycles have no significant effect on volume change. These two findings are similar to the result obtained by Ahmed and Ugai (2011). Kamai et al. (2013) also suggested that recycled basanite achieve the acceptable durability of soft clay when used with certain cement content. Earlier wetting-drying cycle are harmful to durability than later cycle. Ahmed et al. (2014) studied the stability of clay soil with high plasticity stabilized with recycled gypsum, cement, and lime. Ahmed et al. (2014) studied the effect of soaking condition in wet environment on the durability of soft soil treated with recycled gypsum. Cement and lime were used as solidification agent and reduced the solubility of gypsum on wet environment. Ahmed et. al. (2014) also found that effect of soaking on volume change is not significant. Ahmed and Ugai (2011) also found that increase in gypsum-cement content increases the durability whereas there is no significant improvement in durability with gypsum-lime content. Based on stability and durability, gypsum-cement admixture with 22.5% and ratio of 1:1 to 2:1 is suitable to achieve optimum durability. Cement was recommended as solidification agent as it improves the durability of soft clay stabilized with gypsum and resists the solubility of gypsum.

2.3.4 Cement, Lime and Fly-Ash treated soil

Parker (2008) studied the durability of silty sand and lean clay stabilized with four different types of chemical stabilizer- class C fly ash, lime, Portland cement, and lime-fly ash ratio (1:4). Freezing-thawing test was done for cement treated sample, vacuum saturation test was done for specimen treated with fly ash, lime and lime-fly ash. To achieve the same 7 days UCS, sand requires 4.4 times more fly ash than cement, 3.6 times more lime-fly ash than cement and 6 times more lime than cement whereas clay requires 10 times more fly ash than cement, 7.5 times more lime-fly ash than cement and 1.8 times more lime than cement. Samples with UCS less than 200 psi were not survived for freezing-thawing cycle. After both freezing-thawing and vacuum saturation test, sand specimen treated with lime-fly ash had significantly higher UCS and retained UCS than the specimen treated with Class C fly ash, lime or cement whereas clay specimen treated with lime-fly ash and class C fly ash had significantly higher UCS than treated with others. In tube suction method, lime-fly ash and cement reduce the dielectric value of sand to marginal rating while no other stabilizer reduces the moisture susceptible of clay to a satisfactory level. Theivakularatnam and Gnanendran (2015) have studied the durability performance of granular soil subjected to wetting-drying and freezing-thawing. Theivakularatnam and Gnanendran (2015) used cement-fly ash combination in the ratio of 3:1 to stabilize the soil. Results showed that when the cement-fly ash binder content was increased from 1.5% to 3%, there was significant UCS values even after 12 cycles of wetting-drying. This result indicates the durability performance of cement-fly ash mix. Samples subjected to wetting-drying action had heavily deterioration when compared to freezing-thawing cycle. Parsons and Milburn (2003) studied the behavior of soil stabilized with lime, cement, fly ash, enzymatic and combination of them. When stabilized soil was subjected to wetting-drying cycle with saline water, there was a reduction in compressive strength due to leaching of calcium. Parsons and Milburn (2003) found that combination of lime-cement results the improvement in performance for different types of soil while fly ash treated soil has also significant improvement in performance. Result from the test showed that for many soils, combination of stabilization results in economic and durable construction of subgrade. Fly-ash treated soil has less percentage of soil loss as compared to lime treated soil when subjected to freezing-thawing. Lime is suitable for fine-grained soil and cement for coarse-grained soil whereas enzymatic soil does not significantly improve the soil properties (Parsons & Milburn, 2003). Bin-Shafique et al. (2010) stabilize both low plastic clay and high plastic clay using different percentage of fly ash and conducted durability test. Research suggested that wetting-drying cycles had insignificant deteriorating effect on soil stabilized with fly ash where as freezing-thawing cycles has some deteriorating effect on stabilized soil. Strength loss up to 40% however strength significantly increased 3 times higher than unstabilized soil and no change in plasticity due to the effect of freezing-thawing. Swelling potential was also increased by the effect of freezing-thawing cycle.

Vertical swell increased rapidly initially and then slow down with the increase in freezing-thawing cycle. Vertical swelling index of stabilized expansive increased by 1% for 10% and 20% fly ash content, and 2 to 3% for unstabilized soil and 5% fly ash stabilized soil. Fly ash stabilization increased the UCS value of soil by 3 to 4 times, reduce the plasticity by 50%, and swell potential by 75%. There was no any significant effect on UCS, plasticity and swell potential due to wetting-drying cycle with tap water however wetting-drying cycle with saline water reduce the plasticity, slight decrease the swell potential but no any change in UCS (Bin-Shafique et al., 2010).

2.3.5 Lime and Fiber Treated Soil

Puppala and Pedarla (2017) studied the improvement technique for Texas expansive soil for both shallow and deep soil and found that soil treated with 8% lime + 0.15% fiber gave the better performance based on the vertical movement of stabilized soil. Muntohar et al. (2012) conducted research on engineering behavior of silty soil. Muntohar et al. (2012) used lime, rice husk ash and polypropylene plastic waste material as stabilizing agent and performance were measured based on UCS test, tensile test and California bearing ratio test. Durability was evaluated by subjecting the stabilized samples to wetting-drying action. Results showed that soil stabilized with lime and rice husk ash mixture and reinforced with plastic fiber was very effective to improve the engineering property of fine-grained clayey soil. Lime and rice husk ash increase the compressive strength by 4 and 5 times, respectively. The addition of fiber increases the tensile strength. Shear strength of soil was increased by the addition of lime and rice husk ash. Cohesion of fiber reinforced lime and rice husk ash increased initially and then decreased with fiber content. Optimum value was found at fiber content of 0.4% based on cohesion between fiber and soil. Fiber reduced the brittleness behavior of stabilized soil. Based on

California Bearing Ratio (CBR), shear strength, failure characteristic, optimum amount of fiber in a mix of soil, lime, and rice husk ash was found to be 0.4% to 0.8% of dry mass. Lime stabilized soil was not resistant to wetting-drying cycle, but the soil stabilized with combination of rice husk ash and lime showed more resistant to durability than lime stabilized. Lime and rice husk ash treated sample loses its strength after 3 cycles of wetting-drying and then a slight increase in strength on further cycle. Longer fiber will be more difficult to uniformly distribute in the soil–fiber interface and resulted a slippage plane in the soil. Thus, it was suggested to limit the fiber length to be less than 50 mm in length (Al-Refei, 1991; Santoni et al., 2001; Jiang et al., 2010).

2.3.6 Cement and Fiber Treated Soil

Yang et al. (2017) found out that the combination of polypropylene fiber and cement increases the early UCS value of loess soil by 3.65 MPa to 5.99 MPa. Addition of cement results for brittle fracture which is adjusted by adding fiber content, fiber change the mode of fracture from brittle to plastic. Yang et al. (2017) suggested that optimum fiber content for reinforcing the loess soil was 0.3% to 0.45 % and optimum length of fiber was 12 mm. The fiber improves the brittle failure pattern. Ghazavi and Roustaie (2010) studied the effect of freezing-thawing cycle on fiber reinforcement kaolinite clay. Research found that with the increase in number of cycles, UCS value decreased for both unreinforced and reinforced soil sample but with the addition of 3% fiber increased the UCS value by 160% for polypropylene fiber stabilized soil before weathering action, 60% for polypropylene fiber reinforced soil after freezing-thawing cycle, 7% for steel fiber reinforced soil. Compared to steel fiber, polypropylene fiber was good to resist the change in height during the freezing-thawing cycle. Considering strength and height, most of the changes occur during the first 7 cycles and after that, the changes were not much significant.

Previous studies have indicated that the fiber content was the most controlling strength parameter (Consoli et al., 2002; Gaspard et al., 2003; Muntohar, 2009).

2.4 Summary of Literature Review

- ♦ Gypsum or lime alone cannot give long-term durability for soil, cement or fly ash is required as a solidification agent.
- ♦ Based on different available researches, the optimum content of lime for soil stabilization is 4% to 6%.
- ♦ Lime stabilization is more suitable for high plasticity clay rather than low plasticity clay. The addition of lime reduces the plasticity index of high plastic soil.
- ♦ The addition of fiber increases the tensile and shear strength and reduce the brittleness behavior of stabilized soil.
- ♦ Longer fiber length may reduce the durability of stabilized soil by resulting in slippage plane failure.
- ♦ Fiber length should not be greater than 2 inches (50 mm).
- ♦ Polypropylene fiber can achieve better durability performance than steel fiber.
- ♦ The required percentage of fiber for stabilization depends on type of soil, normally 0.15% to 3% is used in combination with cement.
- ♦ The addition of cement results the brittleness of stabilized soil which can be adjusted by adding certain percentage of fiber.
- ♦ Rather than using a single chemical stabilizer, a combination of stabilizing agent might be durable and economical to stabilize the soil.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 Introduction

A durability test was performed on commercially available EPK clay soil stabilized with ordinary Portland cement, and polypropylene fiber. The soil was classified by both the Unified Soil Classification System (USCS) and American Association of State Highway and Transportation Officials (AASHTO) soil classification system. Different combination of cement and fiber was used to stabilize the EPK clay soil. To evaluate the long-term performance in natural conditions seems impractical as it takes a very long time to get the result. So, in this research long-term durability is evaluated based on laboratory setup of wetting-drying and freezing-thawing test methods. These methods are completed based on the certain specification and following standard codes where the natural weathering action, cycles of higher temperature and rainfall during summer, and cycles of freezing temperature and normal temperature during winters are simulated in rapid way. For compaction ASTM D698 standard test method was used. Moisture content was determined based on ASTM D2216 standard. ASTM D559 and ASTM D560 were the standard test methods used for wetting-drying and freezing-thawing test, respectively. Portland Cement Association (PCA) specification was used to evaluate the long-term performance of stabilized soil. Test results were also compared to the US Army Corps of Engineers (USACE) durability requirement, American Concrete Institute (ACI) committee durability requirement and Highway Research Board 1961 requirements.

3.2 Materials

Primarily three different types of materials were used for research purpose. EPK clay soil, cement, fiber and their combination were tested at different laboratory conditions.

3.2.1 Soil Type

Commercially available EPK clay type of soil was used for sample preparation as shown in Figure 3-1. The major composition of EPK clay was kaolinite. It contains 97% of Kaolinite (Al_2O_3, $2SiO_2$, $2H_2O$) as per suppliers' information. EPK clay contains ceramic kaolin which offers good forming characteristic and high green strength. This soil is supplied by Edgar Minerals Inc., Edgar, FL. EPK clay passed 100% from No. 200 sieve (i.e., 0.075 mm). As per USCS, EPK clay was classified as High Compressible Silty soil (MH). Based on AASHTO classification system, EPK clay falls under A-7-5 soil classification system. Table 3-1 and Table 3-2 shows the chemical properties and physical properties of EPK clay, respectively.

Figure 3-1: EPK Clay sample

Table 3-1: Chemical analysis of EPK clay (Edgar Minerals Inc.)

Chemical Composition	**Percent (%)**
SiO_2	45.73
Al_2O_3	37.36
Fe_2O_3	0.79
TiO_2	0.37
P_2O_5	0.236
CaO	0.18
MgO	0.098
Na_2O	0.059
K_2O	0.33
Loss on Ignition (LOI)	13.91

Table 3-2: Physical properties of EPK clay (Edgar Minerals Inc.)

Specific Surface Area (m^2/g)	28.52
Median Size of Particle (Microns)	1.36
Color	White fired color

3.2.2 Cement

Commercially available Quikrete Portland cement, Type I/II of specific gravity 3.14 was used as solidification agent for soil stabilization. Specific gravity of cement was determined at a laboratory using Ultra Pycnometer (Gas pycnometer). Cement was available in gray-brown powder form as shown in Figure 3-2. The cement meets the ASTM C 150 and Portland cement requirement.

Figure 3-2: Ordinary Portland Cement

3.2.3 Fiber

Polypropylene fiber was used in combination with soil and cement for stabilization purpose. The length of fiber was 0.25 inches (6 mm). It come in lump form as shown in Figure 3-3, so it need to be separated before mixing with soil. Uniform distribution of fiber in soil-cement mix determines the efficiency of combination. For better uniform distribution, fiber needs to be separated in each piece from the lump. Specific gravity of fiber was 0.93, determined by using Ultra Pycnometer (Gas pycnometer). The properties of polypropylene fiber are shown in Table 3-3.

Figure 3-3: Polypropylene fiber

Table 3-3: Properties of polypropylene fiber (Dahal, 2016)

Material	**Polypropylene fiber**
Form	Monofilament Fiber
Specific gravity	0.93
Tensile strength, ksi (MPa)	83-96 (570-660)
Length in. (mm)	1/4 (6)
Color	White
Acid/Alkali Resistance	Excellent
Absorption	Nil
Compliance	ASTM C-1116

3.2.4 Soil-Cement-Fiber Mixture

EPK clay was mixed with two different proportion of cement and fiber to prepare the sample. Ordinary Portland Cement 5% and polypropylene fiber 0.5% were mixed with EPK clay to prepare one set of samples. For another set of samples, 10% cement in combination with 0.5% fiber was mixed with EPK clay. In total, five sets of samples, EPK clay, EPK clay + 5% cement only, EPK clay + 5% cement + 0.5% fiber, EPK clay + 10% cement only, and EPK clay + 10% cement + 0.5% fiber were prepared and subjected to wetting-drying and freezing-thawing test.

3.3 Testing and Characterization of Materials

Various characterization of testing material- soil and soil-cement-fiber mixture was conducted. Soil classification, particle size distribution, and Atterberg limit were performed in original EPK clay. Based on Atterberg limit value, soil classification was done. Specific gravity test, miniature Proctor test, SEM/EDAX, and X-Ray diffraction were conducted on original soil and combination of clay, cement, and fiber at various percentage.

3.3.1 Moisture Content

Moisture content also termed as water content, of specimens was determined using ASTM D2216 'Test Method for Laboratory determination of water (moisture) content of soil and rock by mass'. For the mass of less than 200 gm, mass is measured to nearest 0.01 gm. If the mass of the specimen is over 200 gm, mass is measured to nearest 0.1 gm. Mass must be dried by at uniform temperature of 110 ± 5^{o}C for at least 16 hours. However, the time required to oven dried depends upon the size of the specimen and oven type. If the size of specimen is large, mass must be dried until constant mass. Similarly, in this research purpose, to determine the oven-dried mass of standard proctor specimens, they were dried until the constant mass. Proctor samples required more than 72 hours for constant oven-dried mass.

Moisture content is determined by the following relation:

$$MC\ (\%) = \frac{MM-OD}{OD} * 100$$

Where,

MC = Moisture Content of specimen, %

MM = Moist Mass of the specimen (original mass)

OD = Oven Dried Mass of specimen

3.3.2 Particle Size Distribution

EPK clay passes more than 90% from No. 200 sieve so hydrometer analysis was required for particle size distribution. Hydrometer analysis was done based on ASTM D422 'Standard test method for particle size analysis of soil'. ASTM 152H hydrometer, shown in Figure 3-4, was used for particle size analysis. Hydrometer analysis is based on Strokes' law assuming spherical soil particle.

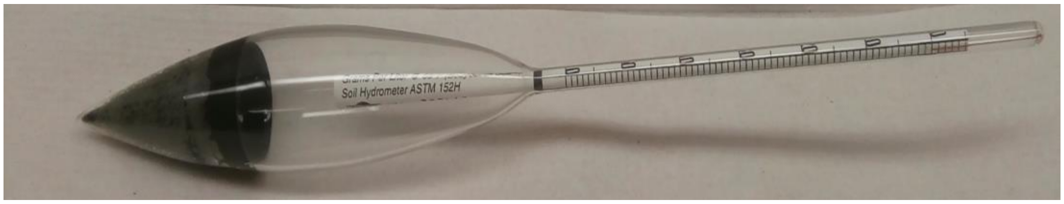


Figure 3-4: ASTM 152H Hydrometer

Due to the charged clay particles, floc may form during hydrometer analysis that results in the false reading. To neutralize the charge on particle, hexametaphosphate is used as a dispersing agent. Hexametaphosphate ($NaPO_3$) is commonly known as Calgon. The general procedure for hydrometer analysis is as described below:

- Weight out 50 gm of oven dried EPK clay passing thoroughly No. 200 US Sieve. Soil is mixed with 125 ml of 4% Calgon solution and keep it for at least 16 hours.
- Prepare the control jar by adding 125 ml of 4% Calgon, stir the solution thoroughly and add enough distilled water to make it 1000 ml. This can be done by adding 5 gm of Calgon in 1000ml distilled water. Place hydrometer in control jar and take reading for zero correction.
- After 16 hours of soaking, transfer the soil water mix to mechanical mixture Figure 3-5, add sufficient water to make it 2/3rd full and mix for about 1 minute.
- Transfer all solution to sedimentation cylinder and add sufficient distilled water up to 1000 ml mark.
- Cap the sedimentation cylinder with a rubber stopper and agitate (turn upside down) the cylinder for 1 minute.

♦ Put the sedimentation cylinder and control jar together in firm surface and starts the stopwatch quickly Figure 3-6.

Figure 3-5: Mechanical Mixture

Figure 3-6: Sedimentation cylinder and Control jar

♦ Insert the hydrometer in sedimentation cylinder and take upper meniscus reading at the cumulative time of 2 min., 5 min., 15 min., 30 min., 60 min., 250 min., 480 min., and 1440 min. After the reading, take out hydrometer from the sedimentation tank and put it into the control jar.

♦ Make appropriate correction for meniscus reading, zero correction (dispersing agent), specific gravity and temperature.

♦ Calculate the percent finer based on the following relation:

$$Rcp = (R + MC - ZC + TC) * GC$$

$$Rcl = R + MC$$

$$L = 16.03 - 0.1641 * Rcl$$

$$D = K * \sqrt{\frac{L}{T}}$$

$$Percent\ finer = \frac{Rcp}{Initial\ Weight} * 100\ \%$$

Where,

L is in cm and T is in minutes

Rcp = Corrected hydrometer reading

Rcl = Corrected hydrometer reading for length

L = Distance from the surface of suspension to the level at which density is measured, cm (effective depth)

D = Diameter of particle

K= Constant depending upon temperature and specific gravity

3.3.3 Atterberg Limit Test

Atterberg limits are the measurement of the critical water content of fine-grained cohesive soil. Solid, semi-solid, plastic and liquid are the four basic stages of soil that depend on water content. These four different stages of soil are separated by boundary water content called Atterberg Limits. Atterberg limits are also called as consistency limits. Atterberg limit test was carried to determine the Liquid Limit (LL) and Plastic Limit (PL) of EPK clay. LL and PL are in turn used to calculate Plasticity Index (PI). Plasticity index is very important geotechnical property of soil that is used in various engineering calculation and classification. The difference between liquid limit and plastic limit is the plasticity index of soil, which is the key tool to measure the plasticity of soil.

PI = LL - PL

Liquid Limit is the critical water content at which behavior of plastic state soil changes to liquid state whereas plastic limit is that water content at which soil behavior changes from semi-solid state to plastic state. Shrinkage limit is also Atterberg limit, but this is not significant as liquid limit and plastic limit.

Figure 3-7: Casagrande's apparatus

Figure 3-8: Cone Penetrometer

For soil classification, Atterberg limit test was carried in according to ASTM D4318 'Standard test method for liquid limit, plastic limit and plastic index of soil' using Casagrande's apparatus Figure 3-7. Later, to determine the relationship of MDD, OMC and cement content with plastic limit, fall cone test method was used. Cone penetrometer, Figure 3-8 was used to determine liquid limit to find out the relationships.

Based on plasticity index value, plasticity of soil can be classified as:

PI = 0, Non-Plastic soil

PI < 7, Slightly Plastic soil

PI = (7 – 17), Medium Plastic soil

PI > 17, Highly Plastic soil

3.3.4 Specific Gravity

Specific gravity of original EPK clay, Cement, Fiber and their combination at two different proportion was determined by gas pycnometer method. The specimen should be oven dried before specific gravity test. Ultrapyc 1200e gas pycnometer was used for specific gravity measurement Figure 3-9. Quantachrome Instruments manufacture the Ultrapyc 1200e which was based on ASTM D5550 ‘Standard test method for specific gravity of soil solids by gas pycnometer’. Oven dried EPK clay, cement, fiber, clay + 5% cement, clay + 10% cement, clay + 5% cement + 0.5% fiber and clay + 10% cement + 0.5% fiber samples were prepared, and specific gravity test was carried out.

Figure 3-9: Ultrapyc 1200e gas pycnometer

Ultra-pycnometer was initially calibrated at target pressure of 15 psi. So, for better result target pressure should be between 15 psi to 20 psi. There should minimum of 6 runs for the most accurate result (ultra-pycnometer manual). Three sizes: large, medium and small are available for test. Small sample holder was used with their adapter for the test. In Main menu, there are nine different types of operation, in which we need basically two types- RUN menu and CALIBRATE menu. Calibration menu is initially used to calibrate with specific sample holder. Pycnometer was already calibrated for small sample holder which was used for test. So, only RUN menu was operated for our test, which in general consists of following submenu.

RUN MENU

1. Run parameter

   i. Target pressure, ii. Equilibrium Time, iii. Purge, iv. Run Mode, v. Cell Size,

   vi. print/send report, vii. Set pressure unit, viii. Set Gas type

2. Sample Parameter

   Manual entry > sample weight gm > sample ID

3. Start

   Press REV to review the result, CLEAR for main menu

Step by Step procedure to calculate sample density and volume using Ultapyc 1200e

1. Setting RUN PARAMETER

- Main Menu > 1-Run > 1- Run parameter > 1- Target Pressure > **15 psi** > enter (to accept new value)/clear to delete error entry
- Main Menu > 1-Run > 1- Run parameter >2- Equilibrium Time > **Auto Mode** (enter 0) > enter/clear (Auto mode take 0 as equilibration time and once the pressure level is stable, it records the pressure value. If pressure is unstable, error will be displayed)

- Main Menu > 1-Run > 1- Run parameter > 3- Purge > 1- Flow > 1 min. > Enter
- Main Menu > 1-Run > 1- Run parameter > 4- Run Mode > 2 – Multi-Run > **6** (multiple run mode) > enter > 6 (runs to average) > **0.005** (run percent deviation) > Enter
- Main Menu > 1-Run > 1- Run parameter > 5- Cell Size > **3** (for small cell size) >Enter
- Main Menu > 1-Run > 1- Run parameter > 6- print/send report > 2- No
- Main Menu > 1-Run > 1- Run parameter > 7- set pressure unit > **0-psi**

  Main Menu > 1-Run > 1- Run parameter > 8- Set gas type > **He**

2. Setting SAMPLE PARAMETER

- Main Menu > 1-Run > 2- Sample parameter > Manual Entry > **enter weight (gm)** > enter sample id > Enter

3. START RUN

- Main Menu > 1-Run > 3- Start

  PRINT-to print result

  REV- to review the measurement

  CLEAR- main menu

- REV > Average volume of all measurement will be displayed > REV > **AVERAGE DENSITY**, standard deviation and sample weight will be displayed

When sample weight is displayed, weight can be changed by pressing clear button and new weight can be assigned. (Low-pressure error condition may occur, press clear and restart the test)

3.3.5 Miniature Proctor Test

Moisture density relationship was found for five different types of soil, cement and fiber combination soil. EPK clay, clay + 5% cement, clay + 10% cement, clay + 5% cement + 0.5%

fiber and clay + 10% cement + 0.5% fiber were five different combination for which miniature proctor test was conducted. For one combination, at least five samples must be made to get compaction characteristic curve. Conducting standard Proctor test for five different combinations require large amount of commercial soil which is not economic. To economize the use of commercially available soil, time, and resources miniature proctor tests were conducted instead of the standard Proctor test to get compaction characteristic curve. Miniature proctor test requires only 1/15th volume of soil needed for standard Proctor test. Also, miniature proctor test is very easy to conduct and require very less time. Result of miniature proctor test for EPK clay sample was compared with the standard Proctor test. They were close enough because of which miniature test was followed for all samples. Miniature Proctor test can be used for fine-grained soil with particle size finer than 2 mm (Sridharan & Sivapullaiah, 2005).

The procedure for determining OMC and MDD from miniature Proctor test is mentioned below:

- Weigh and note down the mass of empty mold of miniature Proctor test apparatus
- Weight approximately 200 gm of fine oven dried soil and add expected water content
- Allow it to absorb moisture for sufficient time and then breakdown the particle and mix thoroughly until the soil color is uniform.
- Place the soil in mold to approximately 1/5th of its volume and compact by spring hammer, 5 times throughout the surface.
- Similarly, compact the soil to five different layers with five blows in each layer.
- Remove the collar, make the top surface smooth and weight the mass of mold and compacted soil. Top surface projection of soil after removing collar should not be greater than 5 mm (Sridharan & Sivapullaiah, 2005)

- Take small quantity of soil from mix and determine the moisture content
- Volume of mold is known; mass of compacted soil can be calculated by deducting mass of empty mold from the mass of mold and soil. Thus, wet density of soil is calculated from the mass of compacted soil and volume using mass, density and volume relationship
- Finally, dry density is calculated from wet density and moisture content relationship.
- Repeat the above procedure for at least five points, two points on dry side and two points on wet side of compaction curve
- Based on the compaction curve, determine OMC and MDD for the soil

$$Wet\ Density = \frac{Compacted\ mass\ of\ soil}{Volume\ of\ mold}$$

$$Dry\ Density = \frac{Wet\ Density}{1 + 0.01 * MC}$$

Where, MC = Moisture Content of soil (%)

Mini compaction test apparatus consists of a base plate, mold, collar plate and spring hammer as shown in Figure 3-10. The internal and external diameter of mold is 1.30 inches and

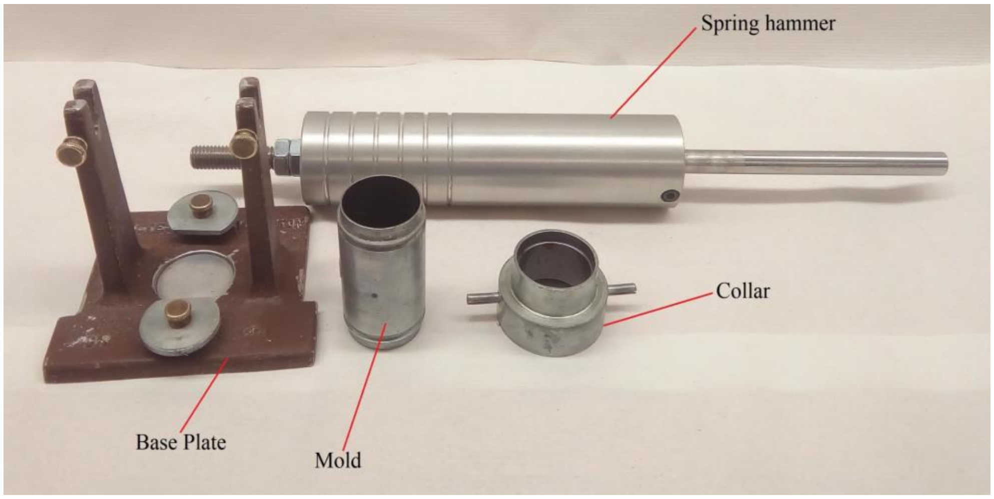


Figure 3-10: Miniature Compaction Test Apparatus

1.50 inches, respectively. The height of mold is 2.825 inches that give 0.00217 ft^3 of mold volume.

3.3.6 Compressive Strength Test

After 12 cycles of weathering action, compression test was done on survived samples as shown in Figure 3-11. The specimens stabilized with 10% cement, 5% cement + 0.5% fiber, and 10% cement + 0.5% fiber were subjected for compression test. Failure load was recorded, final cross-section area was measured, and then compression stress was calculated. The compression test was conducted after 35 days of molding because samples need to be tested for durability test initially and then have to oven dried until constant mass before the compression test.

Figure 3-11: Compression Test

3.3.7 SEM and EDAX Test

Scanning Electron Microscope and Energy Dispersive X-ray Analysis were condcuted in original clay sample and sample mixed with cement and fiber to study the texture and chemical composition of sample. Samples were grinded into powder form and coated with gold/palladium for about 10 minutes before scanning as shown in Figure 3-12 and Figure 3-13. Samples were scanned at magnification factor of 100, 2500, 15000 and 30000 times. For SEM and EDAX, instrument is same but SEM deals with physical morphological aspects like shape and size of grain whereas EDAX deals with chemical composition of materials. Spatial variation in chemical composition, crystalline structure, and orientation of material can be known from the analysis. QuantaTM FEG 450 instrument was used for SEM and EDAX analysis as shown in Figure 3-14.

Figure 3-12: Sample Preparation

Figure 3-13: Sample Coating with Au/Pd

Figure 3-14: SEM/EDAX Scanning Instrument

3.3.8 X-Ray Diffraction Test

X-Ray Diffraction Test was used for the identification of unknown crystalline minerals for stabilized soil. Based on phase identification of crystalline minerals, XRD test provides information on unit cell dimension and quantification of the morphology of crystalline compound. Sample was grinded in very fine powder form and spread into the glass surface making the top face of powder sample smooth. Then the sample was mounted into the diffractometer for scanning as shown in Figure 3-15. Scanning was done by using Cu-Kα radiation with 2Θ ranging from 5 to 90 degree. Rigaku smart lab X-ray diffractometer as shown in Figure 3-16, was used to analyze the mineral composition of EPK clay and clay mixed with different proportion of cement. The XRD data were analyzed with the help of MDI-Jade software.

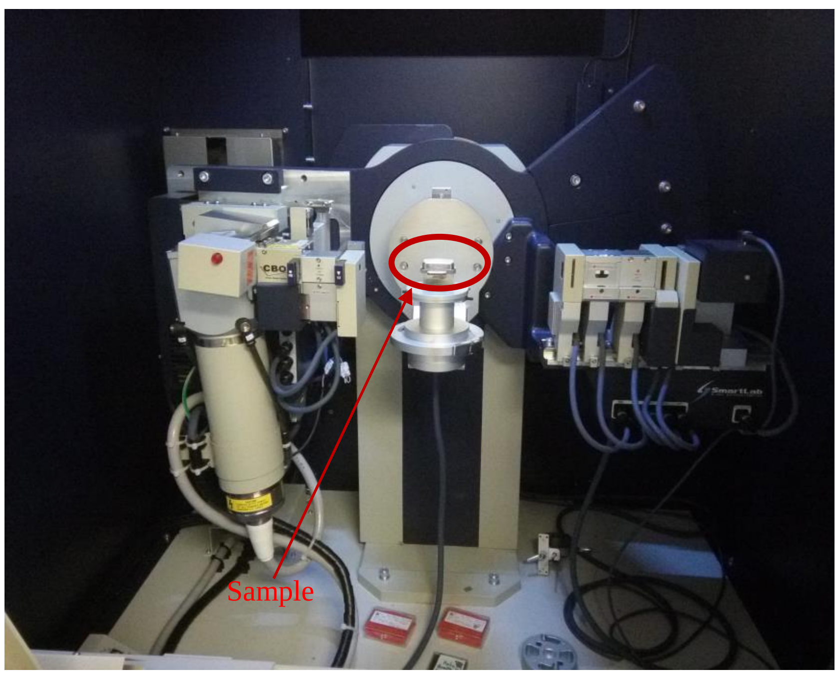


Figure 3-15: Sample mounted in diffractometer

Figure 3-16: Rigaku XRD Test Instrument

3.4 Durability Test Procedure

Durability test was carried out following ASTM D559 and ASTM D560 standard test procedure. In addition to this, compression test was conducted to the survived samples.

3.4.1 Sample Preparation

- ♦ Approximately 5000 gm of soil was prepared in accordance with ASTM D558 Test Method A and mixed with cement confirming the ASTM C150 specification. Initially, soil and cement were dry mixed thoroughly to give a uniform color.
- ♦ Enough potable water was added to soil cement to raise the moisture content to optimum moisture content during compaction. Required amount of water was estimated based on result of miniature proctor test.
- ♦ Soil-cement was mixed and allowed to stand for time of 5 min to 10 min for complete absorption and dispersion of water by soil-cement mix.

- After the absorption, soil cement, and water mix were mixed again and break up the mixture to smaller particle without affecting the natural particle size until it passes through US No. 4 sieve (i.e., 4.76 mm).
- Standard Proctor sample, confirming ASTM D698 specification was prepared immediately after soil preparation.
- Soil was compacted in three layers with 25 blows in each layer with standard Proctor rammer effort of 12400 lbf/ft^2.
- Grooves at right angle with approximately 3 mm width and 3 mm depth at 6 mm apart was sacrificed on the top of first and second layers to ensure the proper bonding between the layers.
- During compaction, representative samples were taken from batch of mixed soil-cement to determine the moisture content of compacted specimen.
- Mass of compacted specimen was recorded, and dry unit of specimen was calculated.
- Obtained moisture content and calculated dry density was checked against design moisture content and designed dry density. OMC should be within tolerance limit of ±1% and MDD should be within the tolerance limit of ±3 lbf/ft^3. If the molded specimen is beyond the tolerance limit specified, another specimen should be compacted.
- Named this specimen as Specimen No. 1 and mold second and third specimen as rapidly as possible in the same way as No. 1 and named as Specimen No. 2 and No. 3.
- Average diameter, height and weight of Specimen No. 1 were measured after molding.
- All the three specimens were stored for a period of 7 days in moist condition protecting from free water. This was done by wrapping the samples with thin plastic, kept it inside

the Ziploc airtight bag and immersed in water. Figure 3-17 shows the samples at the end of seven days storage period.

- ♦ Again diameter, height, and weight were measured after 7 days to calculate water content and volume.

Figure 3-17: Samples after 7 days storage

Two different durability tests i.e., Wetting -Drying and Freezing-Thawing were conducted in five different combinations of EPK clay, cement, and fiber. For each test, Specimen No. 1 (Sample 1) was not brushed during the test while Specimen No. 2 (Sample 2) and Specimen No. 3 (Sample 3) was brushed. These different durability test on various soil combination is shown in Table 3-4. For each combination, miniature Proctor test was conducted, and samples were molded at OMC to get the targeted MDD.

Table 3-4: Durability test of different combination and their notation

Sample Details	Wetting-drying test notation	Freezing-thawing test notation
EPK clay	WD_0C	FT_0C
EPK clay + 5% Cement	WD_5C	FT_5C
EPK clay + 10% Cement	WD_10C	FT_10C
EPK clay + 5% Cement + 0.5% fiber	WD_5C_0.5F	FT_5C_0.5F
EPK clay + 10% Cement + 0.5% fiber	WD_10C_0.5F	FT_10C_0.5F
Sample 1 (Unbrushed)	UB1_WD	UB1_FT
Sample 2 (Brushed)	B2_WD	B2_FT
Sample 3 (Brushed)	B3_WD	B3_FT

3.4.2 Wetting-Drying Test (ASTM D559)

1. Specimens were submerged in potable water for 5 hours and then removed as shown in Figure 3-18. In addition to mass measurement for all samples, diameter and height were measured for Specimen No. 1 for volume calculation. This represents the wetting action of the weathering cycle.
2. After wetting phenomenon, specimens were placed in oven at 71 ± 3^{o}C (160 ± 5^{o}F) and removed after 42 hours. Again, the mass of all specimens along with height and diameter of Specimen No. 1 were measured. This was the drying action of weathering cycle.

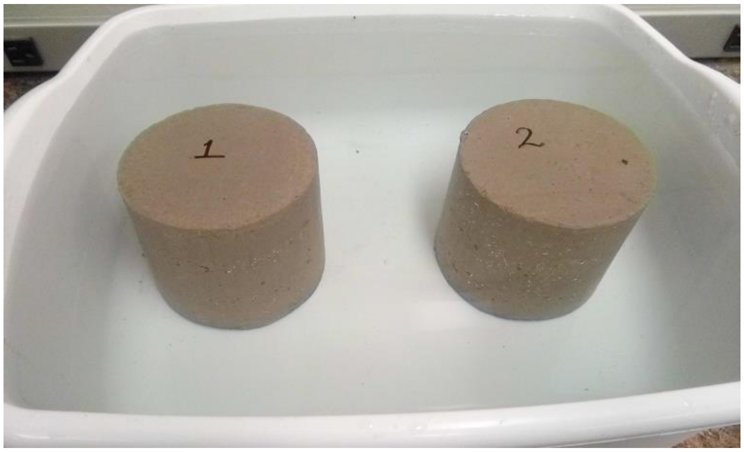


Figure 3-18: Samples submerged in water

3. For Specimen No. 2 and 3, 3 lbf (13 N) force stokes was given on all area with standard wire scratch brush. Two strokes should be given in all area. Generally, 18-20 stokes were required to cover the face twice, and each end requires 4 stokes to cover twice. This represents the deterioration factors that may occur in service life. To apply 3 lbf force stroke, specimen was clamped in weighing balance vertically on edge and zero set the reading Figure 3-19. Then force was applied vertically until the reading shows 3 lbf. By

Figure 3-19: Specimen subjected to brushing

this way, calibration of individual force was done, and the same force was applied on each end of sample without clamping on weighing balance.

4. Mass of all specimen, and height and diameter of Specimen No. 2 and 3 were measured.
5. This completes the one cycle of wetting-drying process. Step 1 to step 4 were repeated 12 times to complete 12 cycles of weathering actions.
6. When the volume measurement of Specimen No. 1 is inaccurate due to soil-cement loss, specimen 1 can be stopped before reaching the 12^{th} cycle.
7. At the end of 12 cycles, specimen was dried in oven at 110 ± 5°C (230 ± 9°F) until constant mass.
8. Finally, oven dried mass of all specimens was measured to calculate the soil cement percent due to weathering action.

Samples should be brushed with standard wire scratch brush. Size of brush should be according to the specification of ASTM D559 or ASTM D560. The standard brush consists of five longitudinal rows and ten transverse rows of bristles on 190 mm × 65 mm (7.5 in. × 2.5 in.) wood block. Brush is assembled in 50 groups of bristle. Each group of bristle consists of 10 flat wire bristle that is 50 mm (2 in.) long, 1.6 mm (0.06 in.) wide and 0.5 mm (26 gages) thick as shown in Figure 3-20.

Figure 3-20: Standard wire Scratch Brush

3.4.3 Freezing-Thawing Test (ASTM D560)

1. Specimens were placed in freezing cabinet having temperature not warmer than -23°C (-10°F) for 24 hours as shown in Figure 3-21. Porous stone was placed between the carrier and specimen. After 24 hours specimens were removed from freeze and mass of all specimen along with diameter and height of Specimen No. 1 were measured. This represents the freezing action of weathering cycle.

Figure 3-21: Freezing of samples

2. After freezing action, specimens were placed in moist room (Ziploc tank) having temperature of 23 ± 2°C (73.5 ± 3.5°F) and 100% relative humidity for 23 hours Figure 3-22. Free potable water was made available to porous stone to absorb water by capillary action during thawing period. In addition to the mass measurement of all samples, height and diameter measurement was done for Specimen No. 1 for volume calculation. This is simulation of thawing action.

3. For Specimen No. 2 and 3, 3 lbf (13 N) force stokes was given on all area with standard wire scratch brush. Two strokes on all area should be given carefully. Generally, 18-20 stokes were required to cover the face twice, and each end requires 4 strokes to cover

twice. This represents the deterioration factors that may occur in service life. To apply 3 lbf force stroke, specimen was clamped in weighing balance vertically on edge and zero set the reading. Then force was applied vertically until the reading shows 3 lbf as shown in Figure 3-19. By this way, calibration of individual force was done, and same force was applied on each end of sample without clamping on weighing balance.

Figure 3-22: Thawing of samples

4. Mass of all specimen, and height and diameter of Specimen No. 2 and 3 were measured.
5. After brushing action, specimens were turned over end for end before starting the next cycle.
6. This completes the one cycle of freezing-thawing process. Step 1 to step 5 were repeated 12 times to complete 12 cycles of weathering actions.
7. When the volume measurement of Specimen No. 1 is inaccurate due to soil-cement loss, Specimen No. 1 can be stopped before reaching the 12th cycle.
8. At the end of 12 cycles, specimen was dried in oven at 110 ± 5^{o}C until constant mass.
9. Finally, oven dried mass of all specimens was measured to calculate the soil cement percent due to weathering action.

3.5 Water of Hydration

When the standard Proctor sample of soil-cement mix is oven dried at 110 ± 5^{o}C, there will be still some water retained within the sample. Water reacts with cement and retains in the specimen which is termed as the water of hydration. Thus, the oven dried sample must be corrected for water of hydration. For the determination of water of hydration after the 12th cycle, Specimen No. 1 was oven dried until constant mass. Water retained in Specimen No. 1 even after oven dried is the water of hydration, assuming that there is no loss of soil-cement of Specimen No. 1 throughout the cycle. When Specimen No. 1 is not molded or there is loss of soil cement in Specimen No. 1 during weathering action, the water retained percentage can be used from standard table of ASTM D559 or ASTM D560 as presented in Table 3-5.

Table 3-5: Average water retained values (ASTM D559/D560)

Soil Classification (AASHTO)	**Avg. water retained after oven dried (%)**
A-1, A-3	1.5
A-2	2.5
A-4, A-5	2.0
A-6, A-7	3.5

Water of hydration after the 12th cycle can be found practically as described above but for water of hydration after each cycle should be assumed logically. Water retained percentage after each cycle can be approximately calculated by PCA specification.

3.6 Calculation of Soil-Cement Loss

The result of wetting-drying test and freezing-thawing test was expressed as a percentage loss of soil-cement after the 12th cycle of weathering action. This calculation was based on

ASTM D559 and ASTM D560 standard. For this, oven-dried mass of all three specimens was recorded. The measured oven-dried mass of Specimen No. 2 and 3 was corrected for water of hydration that has reacted with soil-cement in the specimen. In this research, water retained in Specimen No. 1 and value of Table 3-5 were compared and higher value was taken. Soil used was A-7, thus the average water retained value based on ASTM D559 or ASTM D560 standard was 3.5%. This value was compared with water retained in Specimen 1, if applicable, and higher value was used for mass correction.

Soil-Cement loss percentage was calculated using the standard relations specified in ASTM D559/ASTM D560 standard. Calculated soil-cement loss percentage was compared with PCA specification for durability of specimen.

$$CODM = \frac{ODM}{100 + WR}$$

$$Soil - Cement\ Loss, (\%) = \frac{CaDM - CODM}{CaDM} * 100$$

Where,

CODM = Corrected Oven Dry Mass

ODM = Final Mass Oven Dried at 110 ± 5^{o}C after end of cycle

WR = Water of hydration Retained in specimen

CaDM = Original Calculated oven Dry Mass

3.6.1 Estimation of Soil-Cement Loss in Wetting-Drying test

Calculation of approximate soil-cement loss during wetting-drying cycle was done in accordance to the PCA specification. For the accurate estimation of cement requirement before the completion of test, it is necessary to calculate the soil-cement loss before the completion of test. During the wetting-drying test, the amount of water retained in specimen after oven dried at

71^{o}C is higher than the amount of water retained when oven dried at 110^{o}C. The values of water retained in specimen after oven dried at 110^{o}C, given in Table 3-5 is increased by 3% for the approximate calculation of soil cement loss after oven dried at 71^{o}C. PCA suggests that sample oven dried at 71^{o}C has 3% higher water retained than the specimen oven dried at 110^{o}C. Once the water retained percentage is known, dry weight of sample can be calculated. This dry weight of sample is in turn used to calculate the soil cement loss percentage at any cycle.

3.6.2 Estimation of Soil-Cement Loss in Freezing-Thawing test

Estimation of oven dry mass after each cycle is necessary before calculating the soil cement loss percentage. Thus, PCA made an assumption on moisture based on initial molded moisture content for the calculation of oven-dried mass during freezing-thawing test. PCA suggest after the end of any cycle, specimen contains the moisture content higher than the initial molded moisture content. This amount of excess moisture content as per PCA is given in Table 3-6. Based on Table 3-6, approximate oven dried weight of sample and soil cement loss percentage can be calculated. This method gives the values in more safe side and is not accurate. For this research, moisture content after each cycle end was estimated by backward calculation, utilizing the concept of PCA specification and taking 12th cycle as reference whose oven dried weight is known. Calculated soil cement loss based on this assumption are not obviously exact.

Table 3-6: Moisture content estimation in freezing-thawing test (PCA Handbook, 1992)

OMC	Approximate Moisture Content
<10	Molded moisture content
10-15	Molded moisture content + 1.5%
15-20	Molded moisture content + 2.5%
>20	Molded moisture content + 3%

3.7 Durability Criteria

3.7.1 PCA Soil Cement Laboratory Handbook Durability Requirement

The percentage loss of soil after 12 cycles of wetting-drying and freezing-thawing for durability of stabilized soil should be less than the limits of value shown in Table 3-7 as set by PCA specification.

Table 3-7: PCA specification for durability test (PCA Handbook, 1992)

AASHTO Soil Group	USCS Soil Group	Mass loss (%)
A-1, A-2-4, A-2-5, A-3	GW, GP, SW, SP, SM, GM, SC	≤14
A-2-6, A-2-7, A-4, A-5	CL, ML, MH, CH	≤10
A-6, A-7	CL, CH, OH, MH	≤7

In addition to the above percentage mass loss criteria, PCA handbook mentioned the following additional criteria-

i. Maximum water content should always be less than the water content required for saturation at time of molding.
ii. Compressive strength should increase with age and cement content.
iii. The above cement content is enough for pavement as per PCA criteria.

3.7.2 Highway Research Board 1961

Highway Research Board 1961 gave the range of UCS for moist cured 7 days and 28 days specimen as shown in Table 3-8. The specimen was soaked in water before test.

Table 3-8: Range of UCS cement stabilized soil (Highway Research Board 1961)

Soil Type	7 days wet Compressive Strength MPa (psi)	28 days wet Compressive Strength MPa (psi)
Sandy and gravelly soils A-1, A-2 and A-3 (GW, GC, GP, GF, SW, SC, SP and SF)	2.07-4.14 (300-600)	2.8-6.9 (400-1000)
Silty soils A-4 andA-5 (ML and CL)	1.7-3.45 (250-500)	2.07-6.21 (300-900)
Clayey soils A-6 and A-7 (MH and CH)	1.4-2.8 (200-400)	1.7-4.14 (250-600)

3.7.3 USACE durability requirement

USACE proposed the durability requirement in “Soil Stabilization for Pavement Mobilization and Construction manual”. USACE durability requirement is shown in Table 3-9.

Table 3-9: Durability criteria for durability test (USACE, 1984)

Stabilized Soil	Maximum allowable weight loss after 12 wet-dry or 6 freeze-thaw cycles, percent of initial specimen weight
Granular, PI<10	11
Granular, PI>10	8
Silt	8
Clays	6

In addition to the durability requirement for wetting-drying and freezing-thawing test, USACE proposed the following initial cement content for stabilization of soil as shown in Table 3-10.

Table 3-10: Initial cement content requirement for different types of soil (USACE, 1984)

Soil Type	**Cement Requirement by Dry Weight (%)**
GW-SW	5
GP, SW-SM, SW-SC, SW-GM, SW-GC	6
GM, SM, GC, SC, SP-SM, SP-SC, GP-GM, GP-GC, SM-SC, GM-GC	7
SP, CL, ML, ML-CL	10
MH, OH	11
CH	10

3.7.4 ACI committee durability requirement

ACI committee 230 report provides the basic information and guidelines about mixing the cement with soil for soil stabilization. Like other methods, this method also estimates the initial cement requirement for various types of soil as presented in Table 3-11. Also, ACI report provided the range of cement content for the wetting-drying and freezing-thawing durability test.

Table 3-11: Cement requirement for various soil type (ACI committee report, 2009)

AASHTO soil group	**USCS soil group**	**Cement requirement (%)**	**Cement contents for durability test**
A-1-a	GW, GP, GM, SW, SP, SM	3-5	3-5-7
A-1-b	GM, GP, SM, SP	5-8	4-6-8
A-2	GM, GC, SM, SC	5-9	5-7-9
A-3	SP	7-11	7-9-11
A-4	CL, ML	7-12	8-10-12
A-5	ML, MH, CH	8-13	8-10-12
A-6	CL, CH	9-15	10-12-14
A-7	MH, CH	10-16	11-13-15

3.7.5 Packard (1962) Methods

Packard (1962) experimentally found out the minimum cement requirement for wetting-drying and freezing-thawing test weight loss criteria. For different types of soil, different cement content was proposed as shown in Table 3-12.

Table 3-12: Minimum cement content for durability test (Packard, 1962)

Soil Sample	**Minimum cement content for wetting-drying test (%)**	**Minimum cement content for freezing-thawing test (%)**
Gravelly sand	3	3
Loam	3 or less	5
Clay	5	10
Silt	6	12

CHAPTER 4

RESULTS AND DISCUSSION

4.1 General

This chapter mainly discusses the results of the characterization of materials and durability tests. Characterization such as hydrometer test, specific gravity, Atterberg limit and soil type based on value of LL and PI, compaction characteristics i.e., OMC and MDD of different combination are presented in this chapter. SEM/EDAX results and XRD plot are also presented in this chapter. This chapter mainly focuses on result and discussion of two main durability test i.e., Wetting-Drying test and Freezing-Thawing test. Result of compressive strength test on weathered samples is also presented along with percent loss of soil.

4.2 Particle Size Distribution

As EPK clay passes more than 90% from US No. 200 sieve (i.e., 0.075 mm), hydrometer test was conducted for particle size distribution. The result of hydrometer test is presented in Figure 4-1.

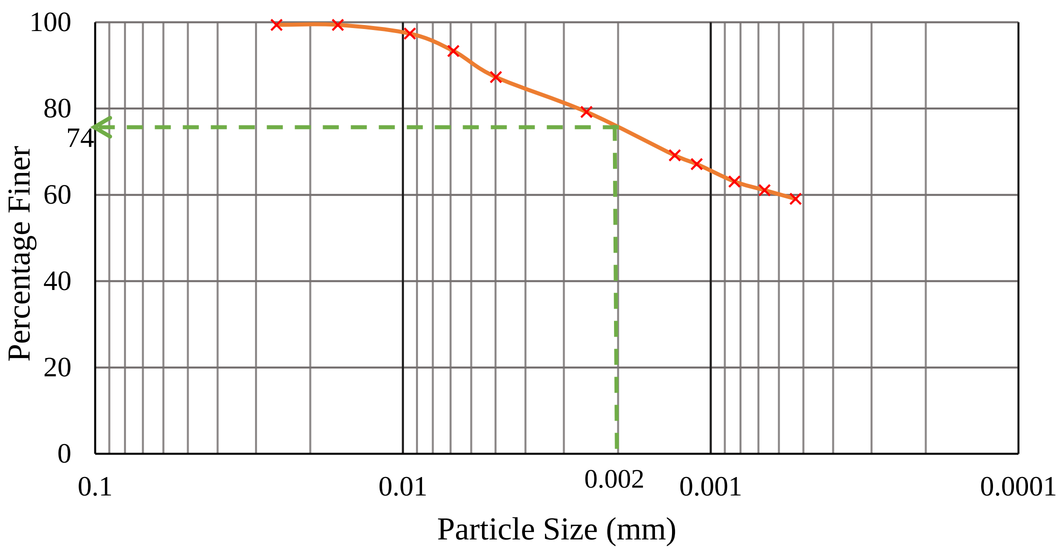


Figure 4-1: Hydrometer Analysis of EPK Clay

From Figure 4-1, it can be observed that 74% of particle is less than 0.002 mm. That means EPK clay contains 74% of clay-sized particle and 26% of silt-sized particle (ranging from 0.002 mm to 0.075 mm).

4.3 Atterberg Limit Test

Atterberg limit was performed to obtain liquid limit (LL) and plastic limit (PL) of EPK clay. From Figure 4-2, it can be observed that the moisture content at 25 number of drops was 58.5%. So, the liquid limit of EPK clay was approximately 58.5 and from the experiment, plastic limit was found to be 33.3. Hence, the plasticity index of clay was calculated as 25.2.

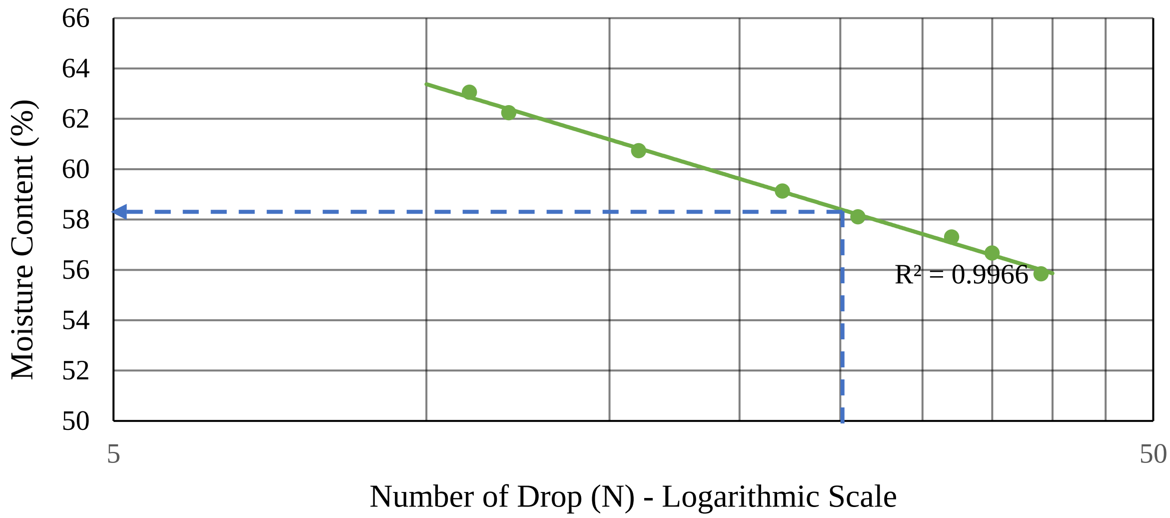


Figure 4-2: Liquid Limit Test of EPK Clay

4.4 Soil Classification

For fine-grained EPK clay, based on result of particle size distribution test and Atterberg limit test, soil was classified in accordance with Unified Soil Classification System (USCS) and American Association of State Highway and Transportation Officials (AASHTO) classification system. Based on USCS plasticity chart, for liquid limit (LL) of 58.5 and plasticity index (PI) of 25.2, soil was classified as High Compressible Silty Soil (MH). Result of Atterberg limit shows that LL > 41 and PI > 11. Hence, the soil is classified as A-7 as per AASHTO soil classification system. Further, PI < LL – 30, confirms that soil was A-7-5.

4.5 Specific Gravity

Specific gravity was calculated for EPK clay, Cement, Fiber, EPK clay + 5% Cement, EPK Clay + 10% Cement, EPK clay + 5% Cement + 0.5% Fiber and EPK clay + 10% Cement + 0.5% Fiber. The result of specific gravity test is tabulated in Table 4-1.

Table 4-1: Specific gravity of different test materials

S.N.	Soil Combination	Specific Gravity
1	EPK Clay	2.590
2	Cement	3.135
3	Fiber	0.930
4	EPK + 5% Cement	2.638
5	EPK + 10% Cement	2.647
6	EPK + 5% Cement + 0.5% Fiber	2.624
7	EPK + 10% Cement + 0.5% Fiber	2.635

From Table 4-1, it can be observed that the fiber has the lowest specific gravity and cement has highest, so the addition of cement in soil increases the specific gravity of soil-cement while the addition of fiber in soil decreases the specific gravity of soil-fiber mix. With addition of 10% cement, specific gravity of EPK clay increases from 2.59 to 2.647 and further addition of 0.5% fiber on EPK clay + 10% cement decreases the specific gravity from 2.647 to 2.635. As the percentage use of fiber was small so there was small variation in specific gravity value.

4.6 Miniature Proctor Test

Miniature compaction test was conducted for five different combinations of soil i.e., EPK clay, cement, and fiber combination. Result of miniature compaction test for EPK clay compared with standard Proctor test and obtained approximately similar value of MDD and OMC from both miniature compaction test and standard Proctor compaction test. Thus, for further compaction test of combination, miniature compaction test was conducted. Result of miniature Proctor test for EPK clay, EPK clay + 5% Cement, EPK Clay + 10% Cement, EPK clay + 5% Cement + 0.5% Fiber and EPK clay + 10% Cement+0.5% Fiber are plotted in Figure 4-3. MDD and OMC for different combination of soil-cement-fiber, based on miniature Proctor test are tabulated in Table 4-2.

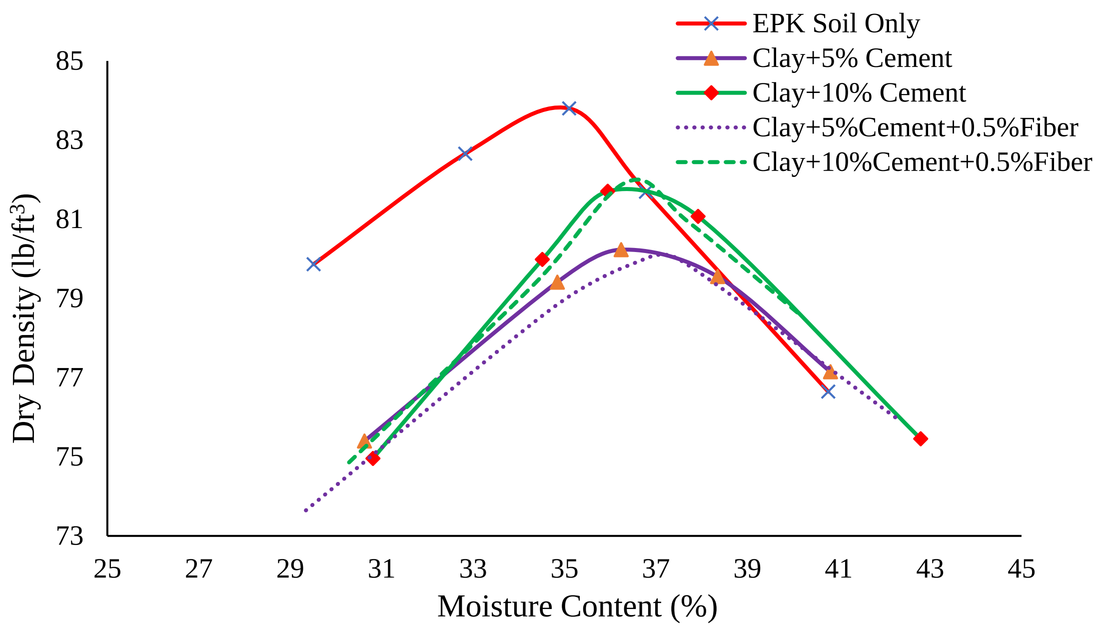


Figure 4-3: Miniature Proctor Test Result

Table 4-2: OMC and MDD for different combination

Combination	**MDD (lb/ft^3)**	**OMC (%)**
EPK Clay	83.8	35.0
Soil+ 5% Cement	80.3	36.5
Soil + 10% Cement	81.8	36.0
Soil + 5% Cement + 0.5% Fiber	80.1	37.0
Soil + 10% Cement + 0.5% Fiber	82.0	36.5

The variation of MDD and OMC with the addition cement were plotted in Figures 4-4 and 4-5. From Figure 4-4 and Figure 4-5, it can be noticed that MDD is maximum and OMC is minimum for EPK clay only (0% cement content) than any other combination. While MDD is minimum and OMC is maximum for EPK clay + 5% Cement.

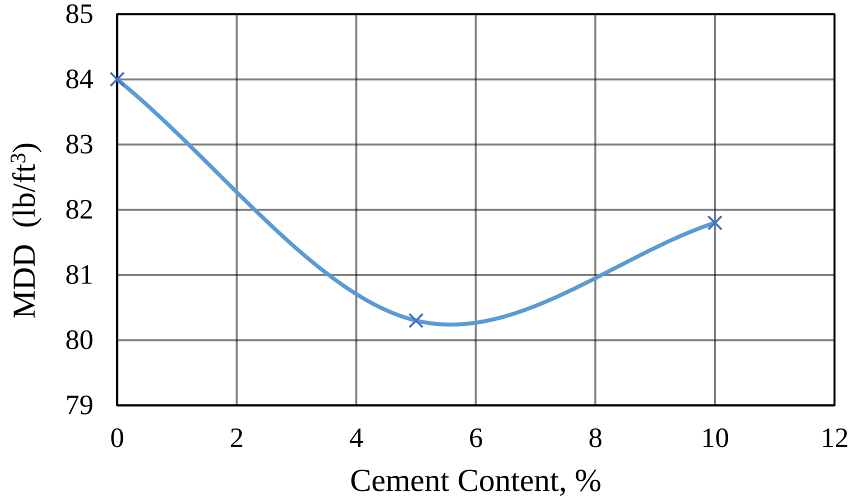


Figure 4-4: Variation of MDD with cement content

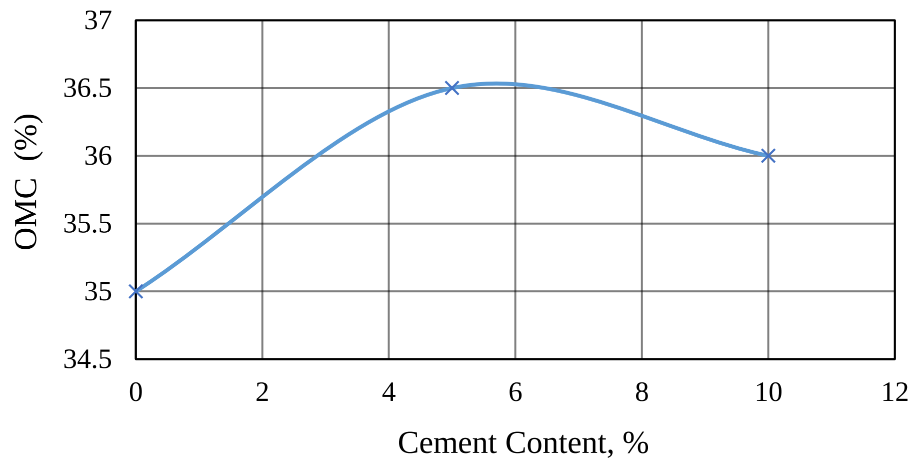


Figure 4-5: Variation of OMC with cement content

The specific gravity of cement is higher than that of clay. Hence, with the addition of cement in EPK clay, it was expected to get the higher density than that of EPK clay, but the results were different than the expected. Even with the addition of different content of cement percentage, behavior is not uniform. With the addition of 5% cement, MDD decreases and OMC increases compared to original EPK clay. With the increase in cement content from 5% to 10%, the behavior is again different i.e., MDD increases and OMC decreases as compared to 5% cement addition. Similar results i.e., initially decrease in MDD with the addition of cement content in soil and further increase the cement content shows the increase of MDD were obtained by Rahman (1987), Muhunthan and Sariosseiri (2008), and Ashraf et al. (2018). Rahman (1987) explained that the variation of MDD with cement content is due to alteration in particle size distribution and specific gravity of soil. Basha et al. (2005) also found that for cement-treated soil MDD is lesser and OMC is higher as compared to untreated soil. The increase in OMC is due to additional water held with flocculant soil structure resulting from cement interaction (Zhang et al., 1996). Sarkar et al. (2012) and Ayininuola et al. (2017) performed the compaction test and obtained the similar results i.e., dry density of cement treated soil decreases than that of untreated soil and OMC of soil increases after cement treatment. Sarkar et al. (2012) explained that for cement treated clay, reduction in dry density was observed because of flocculation and agglomeration of fine-grained soil particles which have higher volume as clay changed to silt because of cement coating thereby forming bigger size particle which occupies larger volume. Ayininuola et al. (2017) also mentioned that cementation and agglomeration of particles of stabilized soil occupy the larger spaces with increase in volume. Ranaivomanana et al. (2018) performed compaction test for natural and cement treated soil and found that dry density decreases after cement treatment. Ranaivomanana et al. (2018) explained the reasons behind the decrease in dry density as cement uses water from the soil for hydration due to which more water is needed to reach sufficient compaction level. For the constant volume of materials, the addition of water increases the water phase volume and decrease the solid phase volume due to which dry density decreases. However, in the current research, it was observed that MDD decreased initially at 5% cement content and again increased at 10% cement content. The cause for this non-uniform variation of MDD with cement content was explained clearly by Chew et al. (2004). Chew et al. (2004) concluded that: “For cement content below 10%, there is only hydration effect and pozzolanic reaction is not supported. Because of hydration reaction, there is formation of large clay-cement cluster thereby resulting larger amount of void and entrapped water which increases liquid limit (LL). Addition of 10% or higher cement content initiates the slower pozzolanic reaction which leads to the attack of Kaolinite. Because of Kaolinite driven pozzolanic reaction, secondary cementitious products deposited around the clay cluster surface thereby increases the particle size but decreases the pore size. Because of the deposition of secondary cementitious products on clay cluster, void sizes and surface activity of clay decreases as a result LL also decreases at higher cement content”. Therefore, based on Chew et al. (2004) at lower cement content there is only hydration reaction that results in the larger sizes of voids. As the void spaces increases, maximum dry density (MDD) decreases. However, at higher cement content, because of the deposition of secondary cementitious products around the clay cluster, void space decreases and the dry density increases. Higher cement content act as a filler agent in flocculated clay particles. The addition of 0.5% fiber has no significant change in MDD and OMC.

4.7 Variation of Plasticity with Cement Content

To study the variation of plasticity with cement content of EPK clay liquid limit (LL) and plastic limit (PL) were carried out and then plasticity index (PI) was plotted with cement content. Liquid limit test was carried out by using cone penetration (fall cone test) method for this study. The result of EPK clay plasticity properties with different cement content is shown in Table 4-3.

The result of LL from Casagrande methods and cone penetration methods for EPK clay is in close range. A similar result was obtained by Muhunthan and Sariosseiri (2008) while calculating LL by Casagrande method and cone penetration method for different types of soil.

Table 4-3: Variation of EPK clay properties with cement content (Fall cone test method)

Cement (%)	**OMC (%)**	**MDD (lb/ft$^{3)}$**	**LL**	**PL**	**PI**
0	35.0	84.0	61.5	33.3	28.2
5	36.5	80.3	77.0	40.5	36.5
10	36.0	81.8	75.5	40.7	34.8

Based on the result of LL and PL; PI for EPK clay with various percentages of cement was calculated and plotted as shown in Figure 4-6. From Figure 4-6 it can be observed that, initially LL increases with the increase in cement content and with the further addition of cement, LL decreases; while PL increases initially and remains relatively constant with the addition of cement content. Initially with the increase in cement content, PI increases and with the further addition of cement PI decreases slightly. Thus, for EPK clay plasticity of soil increases initially with cement content and decreases with the further addition of cement. Chew et al. (2004), and Muhunthan and Sariosseiri (2008) also got a similar result i.e., initially increase in LL and PI with cement content, and then decrease in LL and PI with the further addition of cement while PL increases initially and remains relatively constant with the further addition of cement. Chew et al. (2004) have explained that at lower cement content, larger voids spaces form entrapping the larger water content which is responsible for higher LL whereas at higher cement content void sizes decreases and less water entrapped as a result LL decreases.

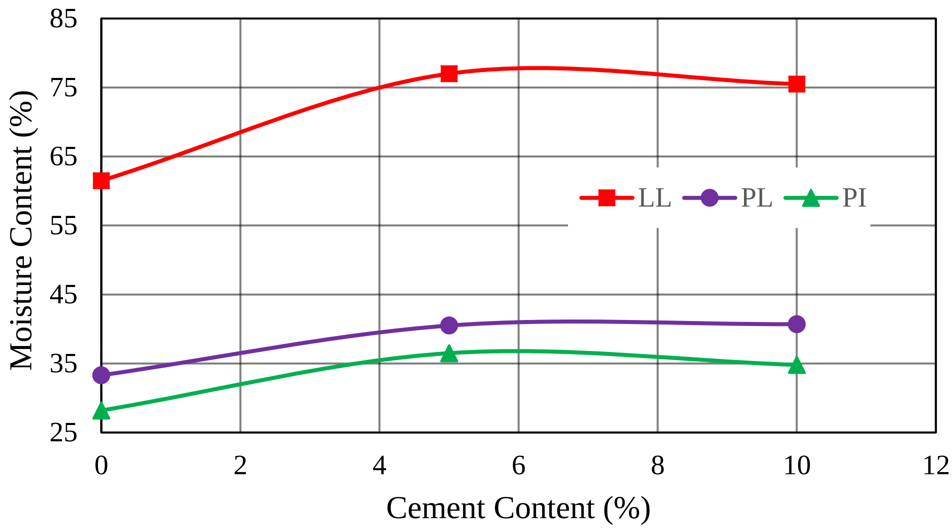


Figure 4-6: Variation of plastic index with cement content

4.8 SEM/EDAX Test

SEM/EDAX test was conducted for the EPK clay and clay mixed with 5% and 10% cement. Results of SEM shows that morphology of EPK clay was a flaky structure. Average particle size was approximately 0.4 micron (400 nm) and particles were conglomerations and randomly oriented. Figure 4-7 shows the SEM scanning result of EPK clay at 15000 times magnification. Figure 4-8 shows the EDAX result of EPK clay only. EDAX result shows that

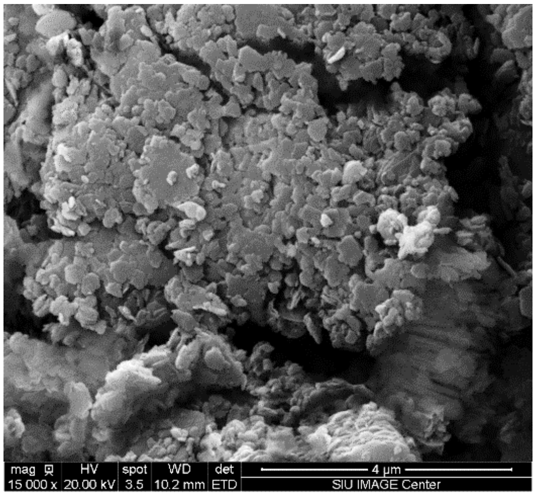


Figure 4-7: SEM image of EPK clay

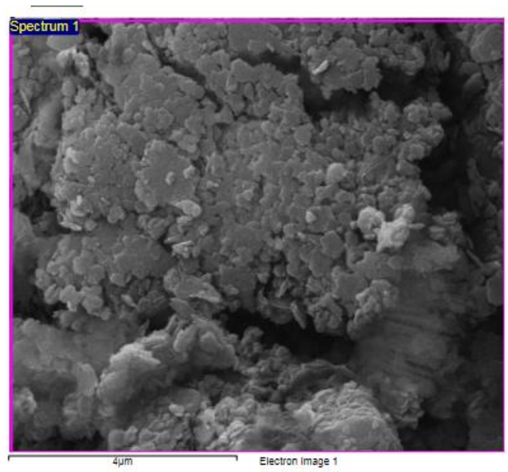
major compositions of EPK clay are Alumina and Silica. Titanium and Iron were also present in a small percentage.

Spectrum processing :
Peaks possibly omitted : 2.154, 2.843 keV

Processing option : All elements analyzed (Normalised)
Number of iterations = 3

Standard :
O SiO2 1-Jun-1999 12:00 AM
Al Al2O3 1-Jun-1999 12:00 AM
Si SiO2 1-Jun-1999 12:00 AM
Ti Ti 1-Jun-1999 12:00 AM
Fe Fe 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
O K	52.35	66.44
Al K	19.14	14.40
Si K	23.96	17.32
Ti K	2.93	1.24
Fe K	1.63	0.59
Totals	100.00	



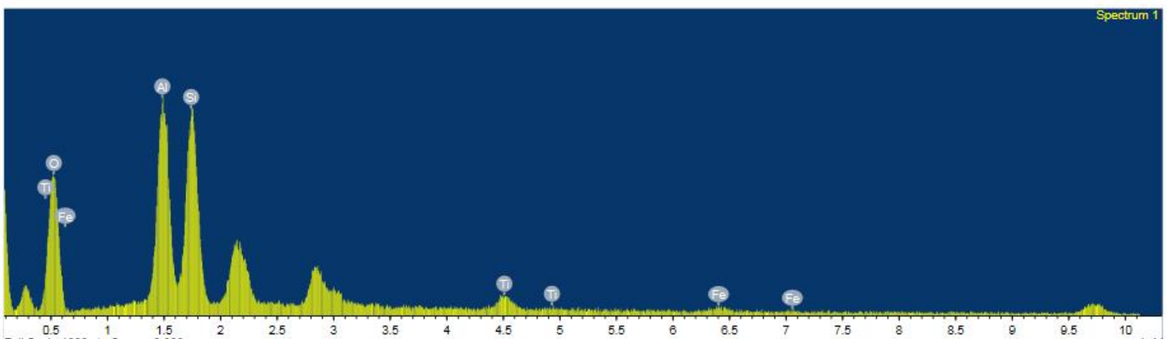


Figure 4-8: EDAX result of EPK clay

Figure 4-9 shows the SEM image of EPK clay mixed with 5% cement, captured at 15000 times magnification. The addition of 5% cement does not have a significant change in morphological aspects of soil-cement. Structure of EPK clay with 5% cement also has randomly oriented flaky type of structure. Figure 4-10 shows the chemical composition of EPK clay mixed with cement and fiber. Alumina and Silica were the major components of the soil-cement mixture. The addition of cement results in the presence of calcium in the soil-cement.

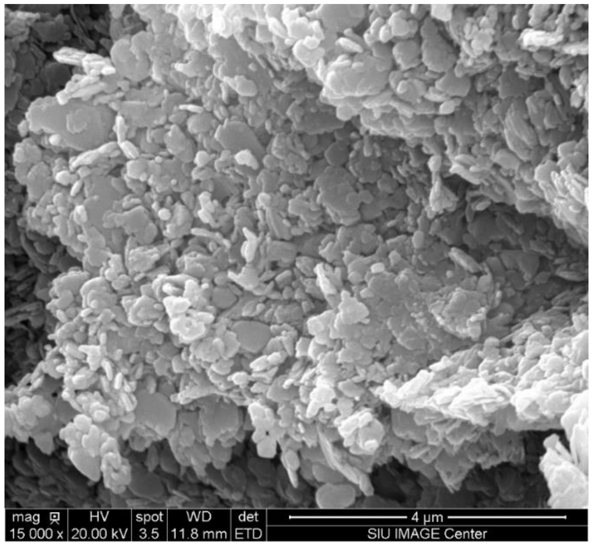


Figure 4-9: SEM image for EPK clay + 5% Cement

Spectrum processing :
Peaks possibly omitted : 2.138, 2.409, 2.842, 3.015, 8.490 keV

Processing option : All elements analyzed (Normalised)
Number of iterations = 3

Standard :
O SiO2 1-Jun-1999 12:00 AM
Al Al2O3 1-Jun-1999 12:00 AM
Si SiO2 1-Jun-1999 12:00 AM
Ca Wollastonite 1-Jun-1999 12:00 AM
Fe Fe 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
O K	46.27	60.48
Al K	21.36	16.55
Si K	28.18	20.98
Ca K	2.90	1.51
Fe K	1.30	0.49
Totals	100.00	

Figure 4-10: EDAX result of EPK clay mixed with 5% cement and 0.5% fiber

Figure 4-11 shows the SEM image of EPK clay mixed with 10% cement and 0.5% fiber, captured at 100 times magnification. Figure 4-12 shows the elemental composition of EPK clay mixed with 10% cement and 0.5% fiber. The result shows that with the increase in cement percentage, the calcium content increases in mixture of soil-cement. Alumina and silica were the major component of soil mixed with 10% cement and fiber.

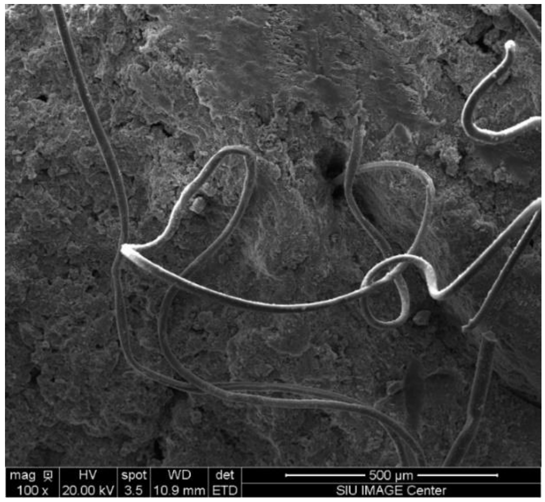


Figure 4-11: SEM result of EPK clay mixed with 10% cement and 0.5% fiber

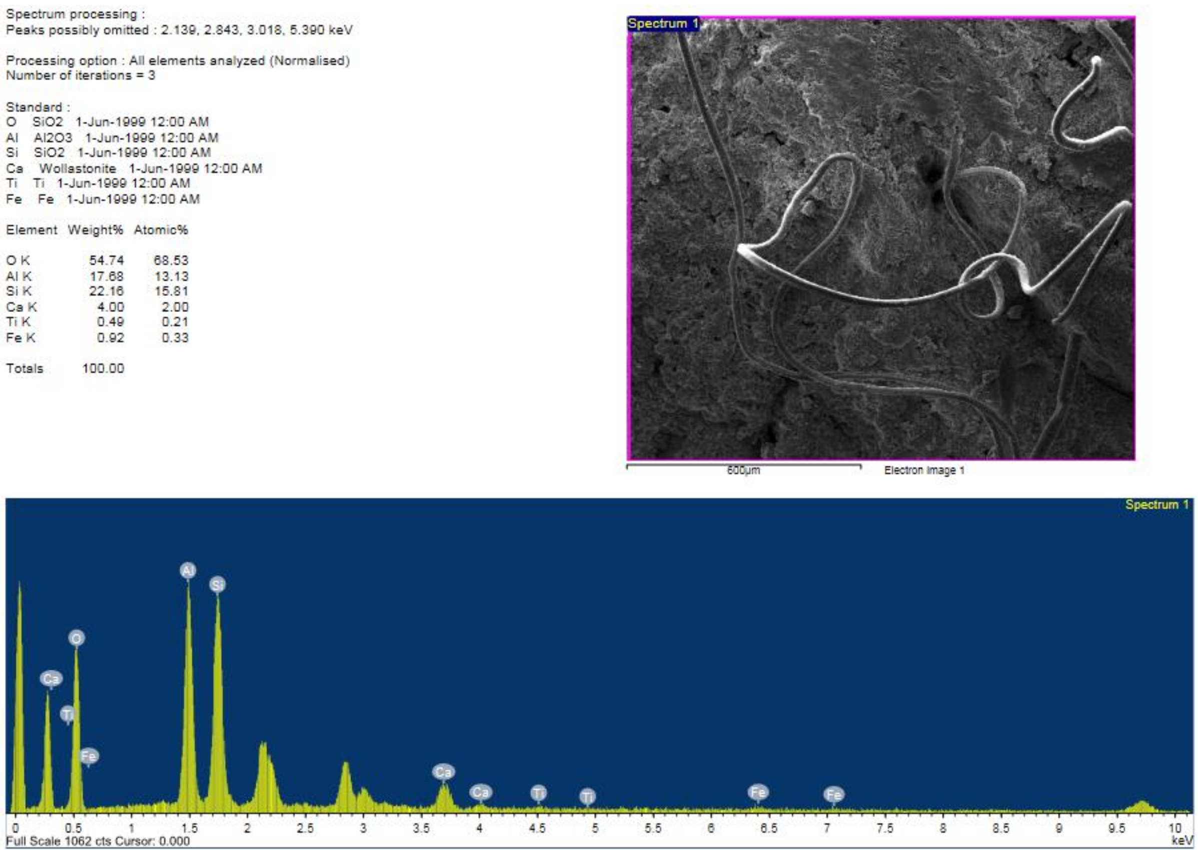


Figure 4-12: EDAX result of EPK clay mixed with 10% cement and fiber

4.9 X-Ray Diffraction (XRD) Test

XRD test was performed on original EPK clay, clay + 5% cement, and clay + 10% cement. Figure 4-13 shows the XRD plot for three different combinations of clay with various percentage of cement. From Figure 4-13, it can be observed that with the addition of 10% cement results in the new intensity peak at $2\Theta = 29.5^o$. Rest of the intensity peak of EPK clay matches exactly with intensity peak of EPK clay + 5% cement and EPK clay + 10% cement. Kaolinite-$Al_2Si_2O_5(OH)_4$ is the dominant minerals in all three combinations of soil-cement mixture. Approximately 97% of mineralogical composition of EPK clay and clay mixed with cement is of Kaolinite. Figure 4-14 shows the XRD test result analysis for mineral identification using MDI Jade software. Based on MDI Jade analysis of XRD result, new minerals formed with the addition of 10% cement was identified as Calcite- $CaCO_3$. The new peak seen in EPK + 10% cement at $2\Theta = 29.5^o$ is of Calcite whereas common mineral in all combination is Kaolinite.

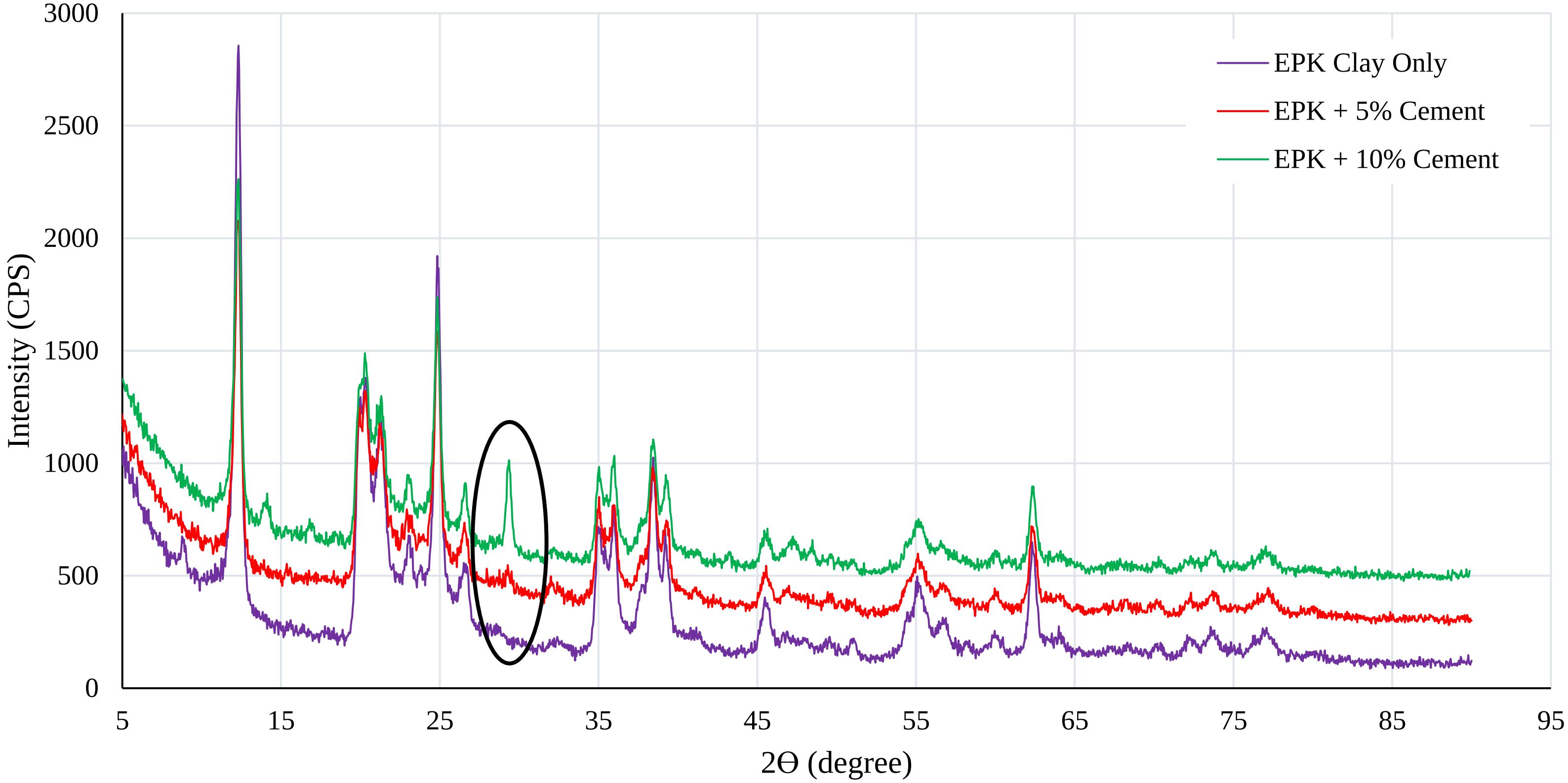


Figure 4-13: XRD plot of EPK clay mixed with various proportion of cement

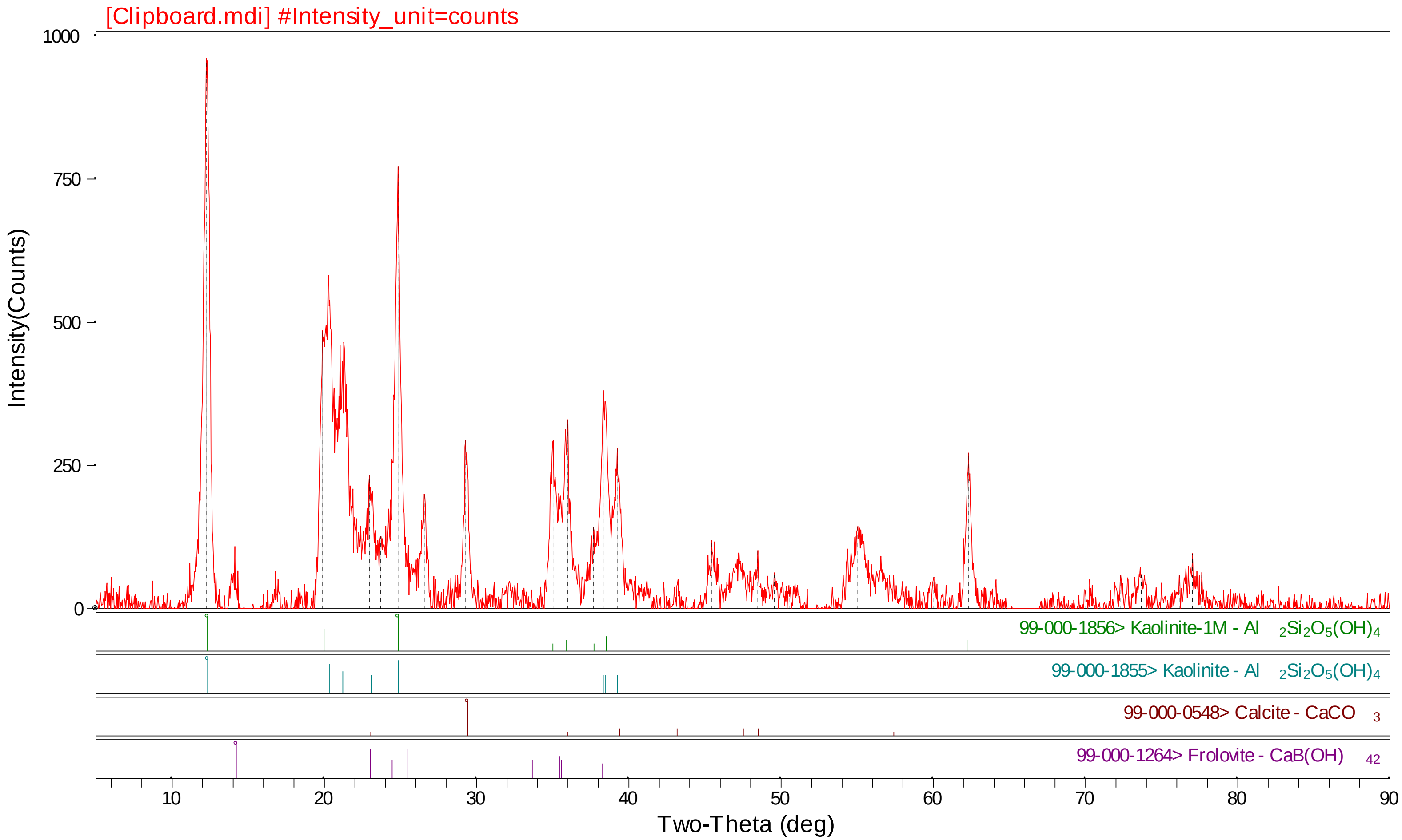


Figure 4-14: XRD result analysis using MDI Jade

4.10 Durability Test Result

Result of two main durability test i.e., wetting-drying and freezing-thawing are presented in terms of percentage loss of soil-cement-fiber after 12 weathering cycle. Also, the compressive strength test of survived samples was carried out at the end of test. Finally, results of the wetting-drying test and freezing-thawing test are compared by plotting results on same graph. Durability was measured based on Portland Cement Association (PCA) soil-cement loss criteria for all combination.

4.10.1 Wetting-Drying Test

4.10.1.a EPK clay (WD_0C)

Three standard Proctor samples of EPK clay were subjected to wetting-drying test. Sample 1 was unbrushed (UB1) and Sample 2 (B2), and Sample 3 (B3) was brushed after drying action. The percentage loss after the end of first cycle was significantly higher and all the samples collapsed completely in the beginning stage of second cycle as shown in Figure 4-15. As the sample collapsed completely, percentage loss of soil and compressive strength of test sample cannot be found. EPK clay (without cement or fiber) is not durable against wetting-drying action. Thus, 5% cement is added and wetting-drying test was carried out to check the durability of 5% cement stabilized soil.

During 2nd cycle (at 0 min. immersion)

During 2nd cycle (After 5 hrs. immersion)

Figure 4-15: Effect of Wetting-Drying on EPK clay (WD_0C)

4.10.1.b EPK clay stabilized with 5% Cement (WD_5C)

With the addition of 5% cement, Sample 2 collapsed in 3rd cycle, and Sample 1 and Sample 3 was stopped after 4th cycle. Due to heavy deterioration of samples, compressive strength test was not conducted. Percentage loss of soil for unbrushed Sample 1 was 16% and for brushed Sample 3 was 26.67% after 4th cycle. The result confirms that EPK clay stabilized with only 5% cement is not durable against wetting-drying test. Figure 4-16 shows the mass of all three samples after each cycle ends. Figure 4-17 shows the volume of the unbrushed sample during wetting-drying test. The increase in volume is due to immersion in water and decrease in volume is due to drying action. Figure 4-18 shows the deterioration condition at various stage of durability test.

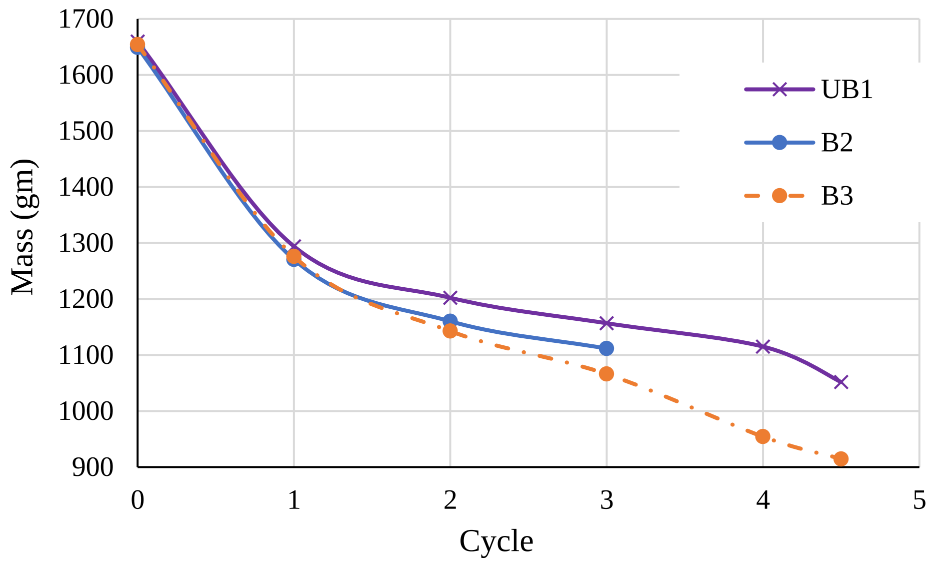


Figure 4-16: Mass change with cycle for WD_5C

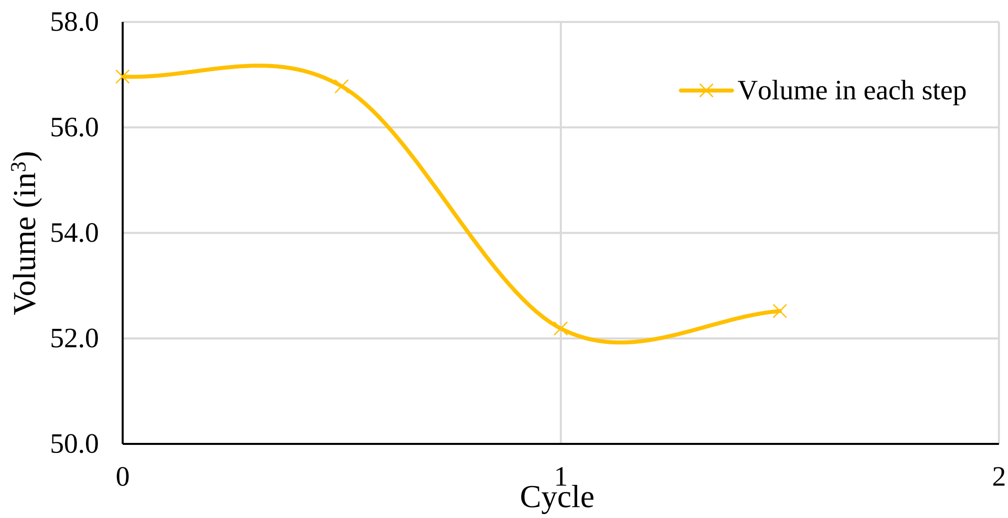


Figure 4-17: Volume change with cycle for WD_5C (UB1)

Before subjecting to cycle 1

Immersion in water during cycle 4

At the end of cycle 4

Figure 4-18: Various stage of wetting-test of WD_5C

4.10.1.c EPK clay stabilized with 10% Cement (WD_10C)

Samples were not durable with 5% cement only, thus cement content was increased to 10% and wetting-drying durability test was carried out. Sample 1 and Sample 2 survived for all 12 cycles of weathering action and Sample 3 collapsed in 10^{th} cycle during brushing operation. Percentage loss of soil for Sample 1 and Sample 2 was 1.63% and 8.68%, respectively. Compressive strength on oven-dried samples at the end of wetting-drying cycles for Sample 1 and Sample 2 was 500 psi and 323 psi, respectively. Percentage loss of soil and compressive strength of collapsed sample cannot be found. Figure 4-19 shows the mass of all three samples after each cycle ends. Figure 4-20 shows the volume of unbrushed sample during wetting-drying test. Figure 4-21 shows the deterioration condition at various stage of durability test for EPK clay sample stabilized with 10% cement.

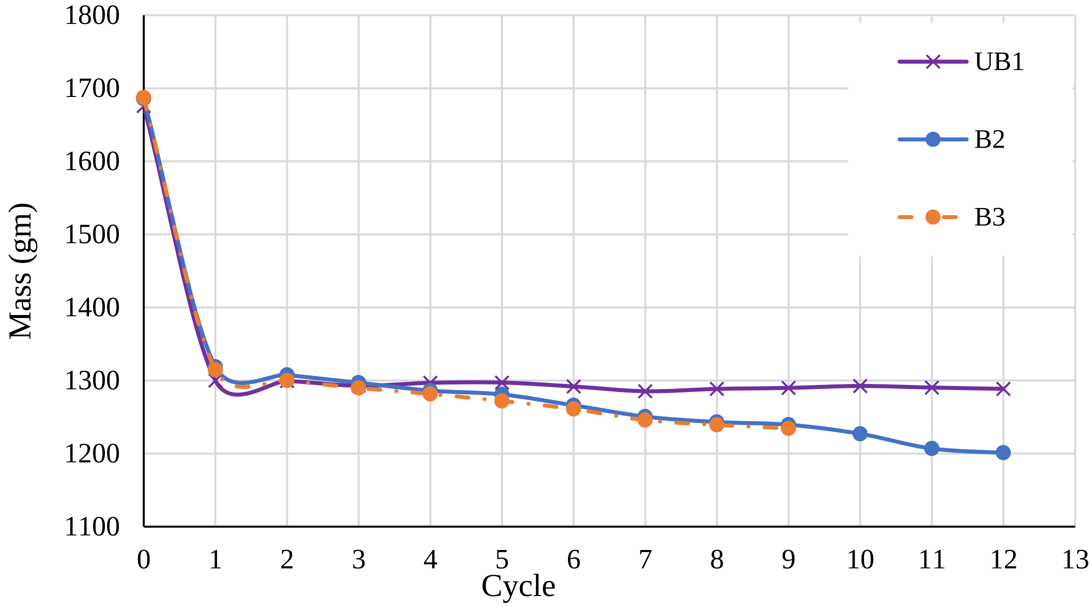


Figure 4-19: Mass change with cycle for WD_10C

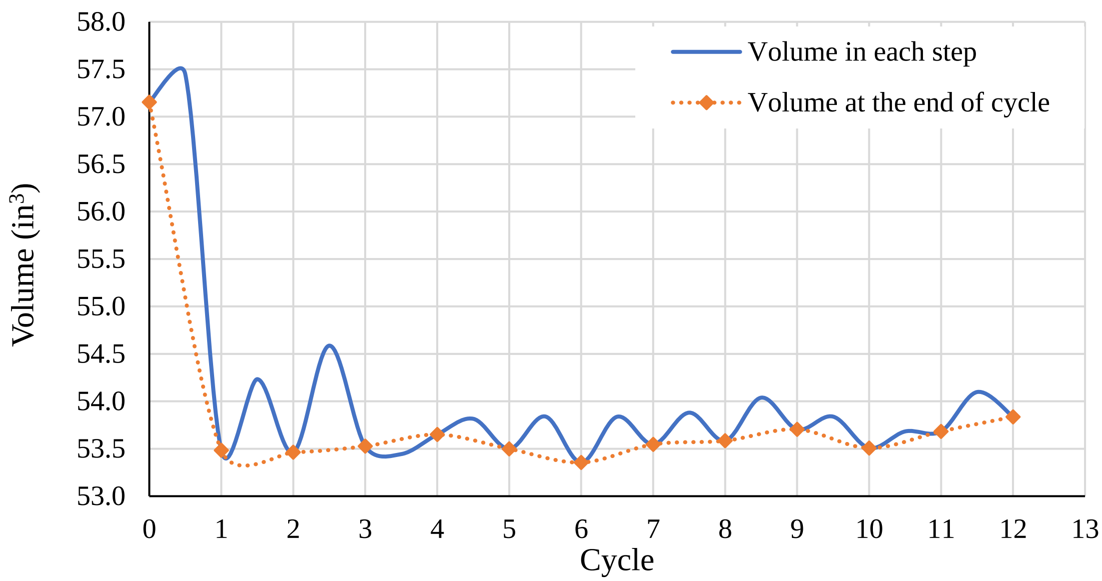


Figure 4-20: Volume change with cycle for WD_10C (UB1)

During 1st cycle

Sample 3 during 10th cycle

Sample 1 and sample 2 after 12th cycle

Figure 4-21: Various stage of wetting-drying test of WD_10C

Combining PCA concept and final oven-dried mass of sample after 12th cycle as reference, approximate moisture content of samples in each cycle was estimated. By using this moisture content, approximate soil-cement loss percentage was calculated as shown in Figure 4-22. The soil-cement loss percentage value in each cycle is only an approximate value. Referencing the PCA criteria, the percentage loss of soil-cement of brushed samples should be less than 7% for the durability. In this case, one sample collapsed before the cycle completion, and another sample has percentage loss higher than 7%. Thus, EPK clay stabilized with only 10% is not durable against wetting-drying test.

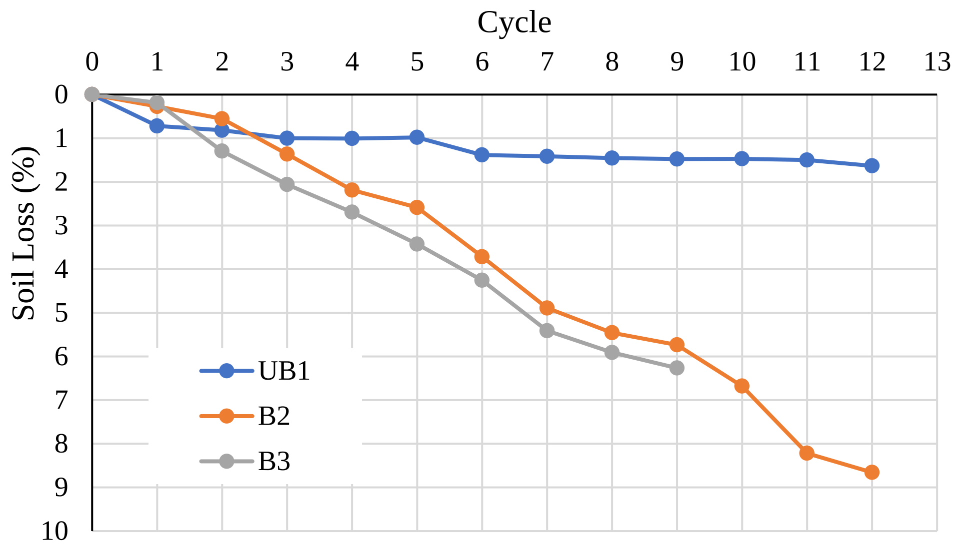


Figure 4-22: Percentage loss of stabilized soil in each cycle for WD_10C

4.10.1.d EPK clay stabilized with 5% Cement and 0.5% Fiber (WD_5C_0.5F)

To increase the tensile strength and durability, cement stabilized samples were reinforced with small percentage of fiber. Addition of fiber results in the survivable of all three samples up to 12 cycles of wetting-drying weathering action. Percentage loss of stabilized soil-cement-fiber of unbrushed Sample 1 was 6.84%, Sample 2 was 20.89% and Sample 3 was 16.20%. Compressive strength of oven dried samples after 12th wetting-drying cycle for Sample 1, Sample 2 and Sample 3 were 737.2 psi, 347.1 psi, and 561.4 psi, respectively. Figure 4-23 shows the mass of all three samples after each cycle ends. Figure 4-24 shows the volume of unbrushed sample during wetting-drying test. Figure 4-25 shows the deterioration condition at various stage of durability test for EPK clay sample stabilized with 5% cement and 0.5% fiber.

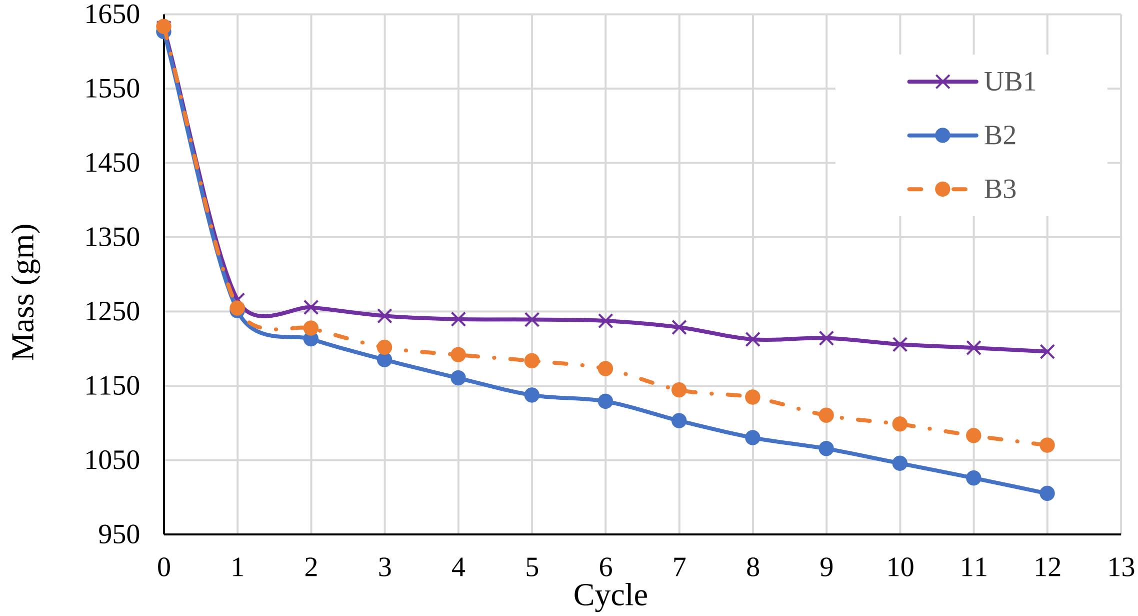


Figure 4-23: Mass change with cycle for WD_5C_0.5F

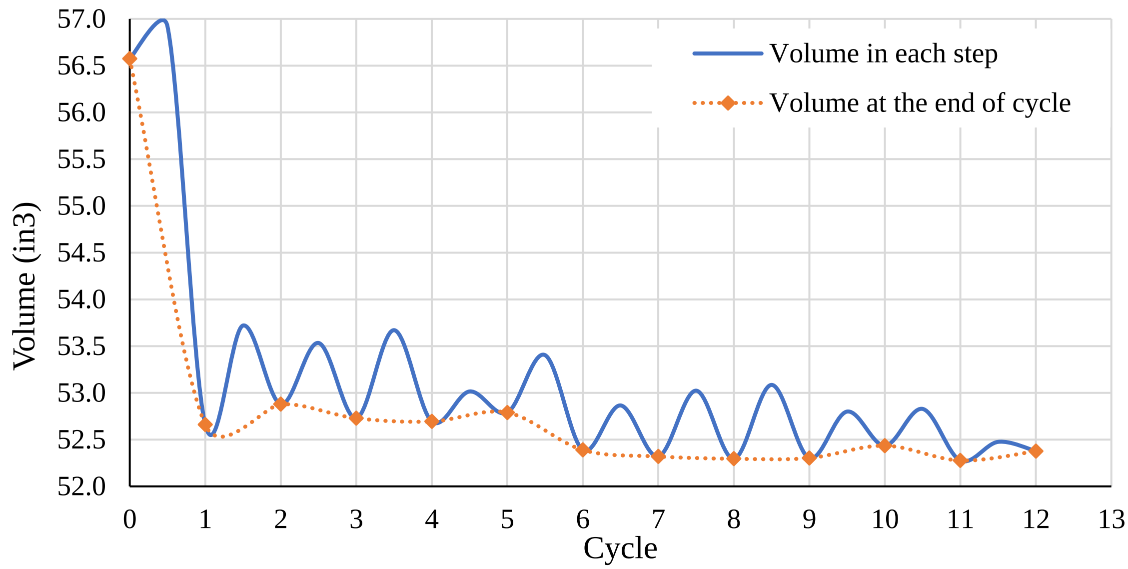


Figure 4-24: Volume change with cycle for WD_5C_0.5F (UB1)

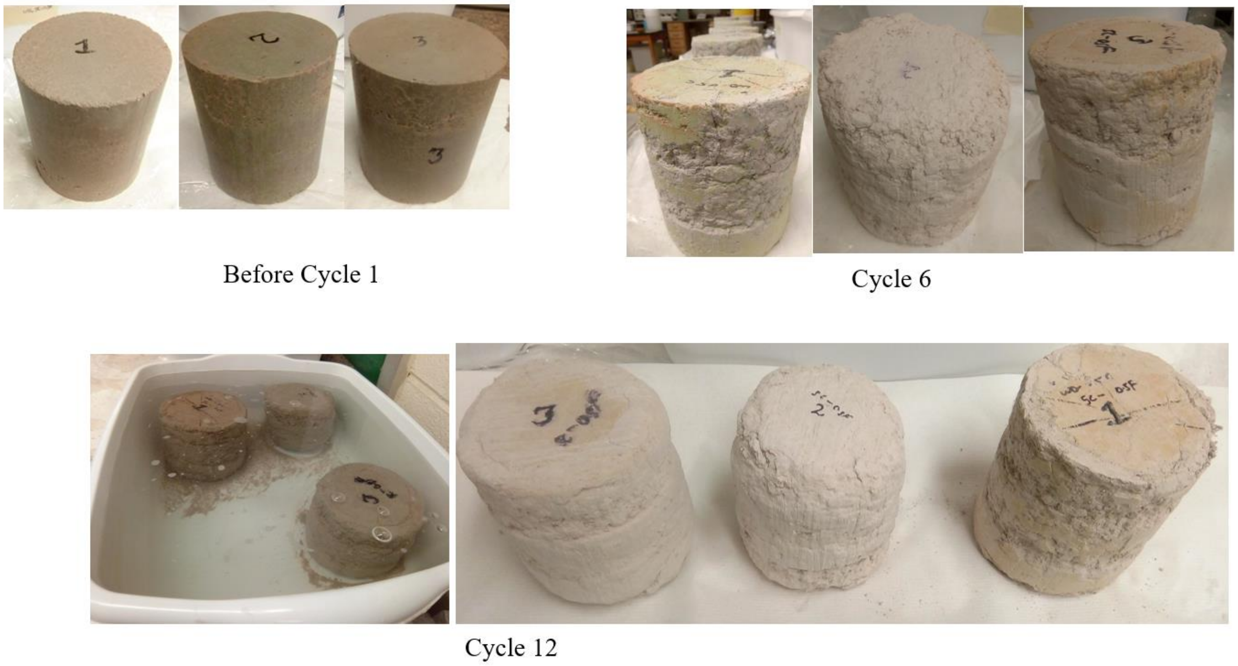


Figure 4-25: Various stage of wetting-drying test of WD_5C_0.5F

Using the concept of PCA moisture content estimation and backward calculation referencing the oven-dried mass after 12^{th} cycle as standard, the approximate percentage loss of stabilized soil was calculated and shown in Figure 4-26. Although all the three samples survived 12 cycle of weathering action, percentage loss due to weathering action is greater than 7%. Thus, EPK clay stabilized with 5% cement and 0.5% fiber is not durable against the wetting-drying test.

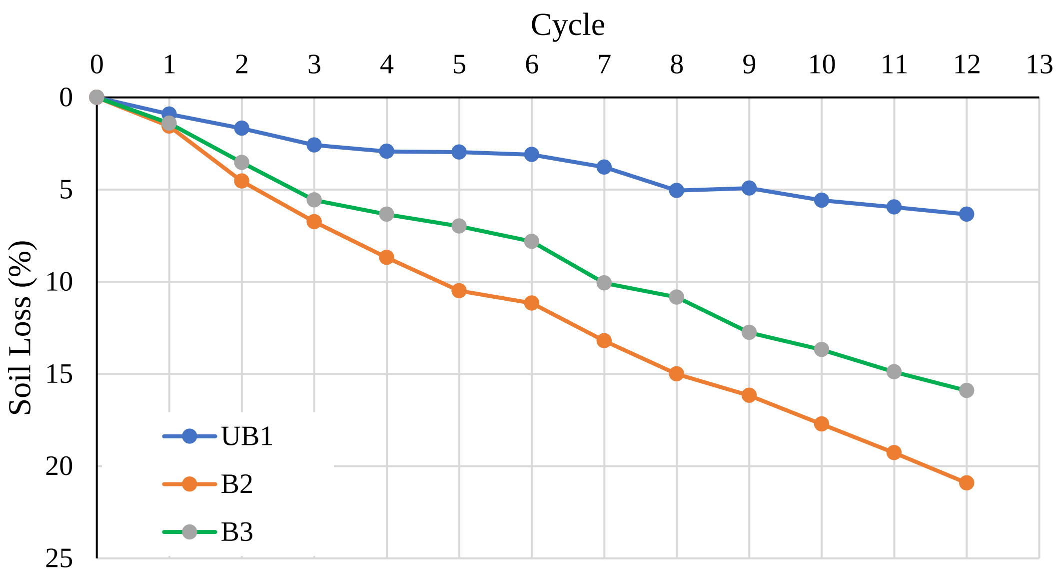


Figure 4-26: Percentage loss of stabilized soil in each cycle for WD_5C_0.5F

4.10.1.e EPK clay stabilized with 10% Cement and 0.5% Fiber (WD_10C_0.5F)

Neither the soil stabilized with 5% cement + 0.5% fiber nor with 10% cement gives the durability of EPK clay against wetting-drying test. So, soil is stabilized with 10% cement and 0.5% fiber and durability test is carried out. Percentage loss of soil-cement-fiber combination of the clay stabilized with 10% cement and 0.5% fiber is 1.61% for unbrushed Sample 1, 6.55% for Sample 2 and 6.39% for Sample 3. Similarly, compressive strength at the end of 12 cycles of weathering action was 1396 psi for Sample 1, 1080 psi for Sample 2 and 1153 psi for Sample 3. Figure 4-27 shows the mass of all three samples after each cycle ends, Figure 4-28 shows the volume of unbrushed sample during wetting-drying test and Figure 4-29 shows the deterioration condition at various stage of durability test of EPK clay sample stabilized with 10% cement and 0.5% fiber.

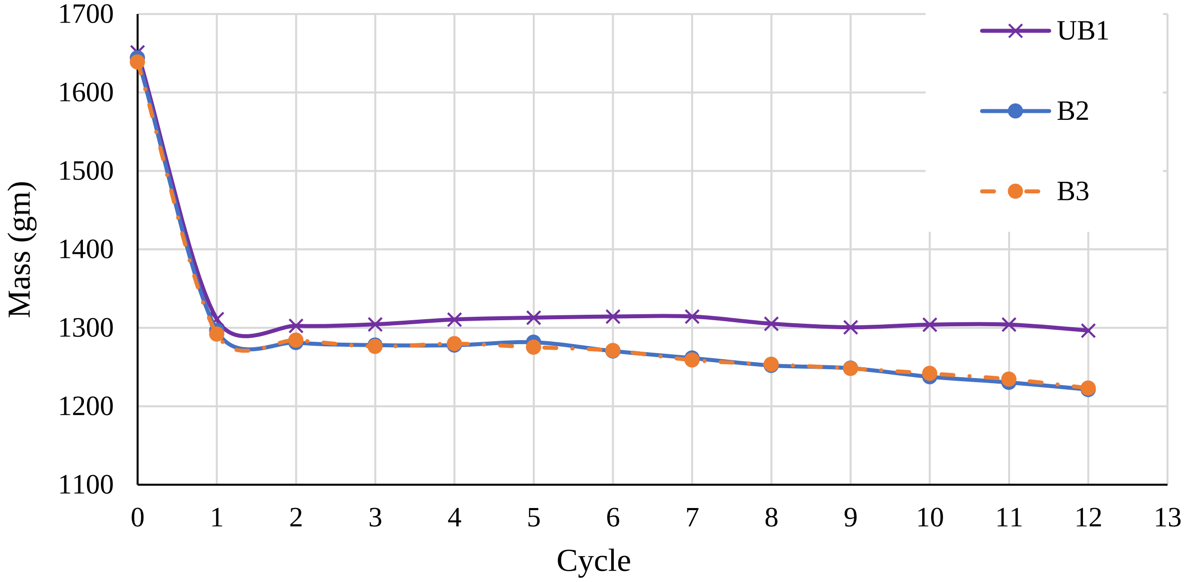


Figure 4-27: Mass change with cycle for WD_10C_0.5F

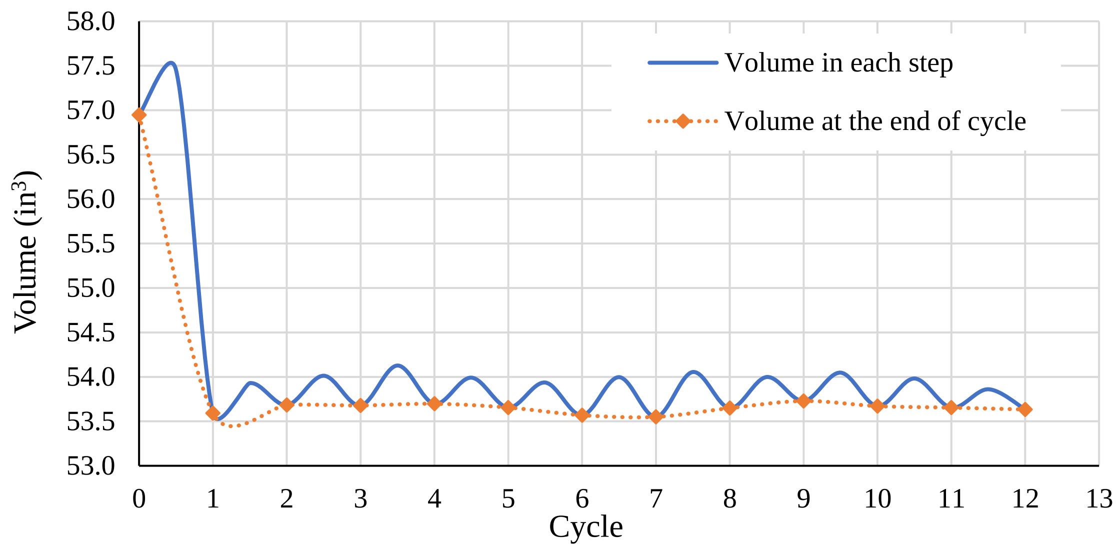


Figure 4-28: Volume change with cycle for WD_10C_0.5F (UB1)

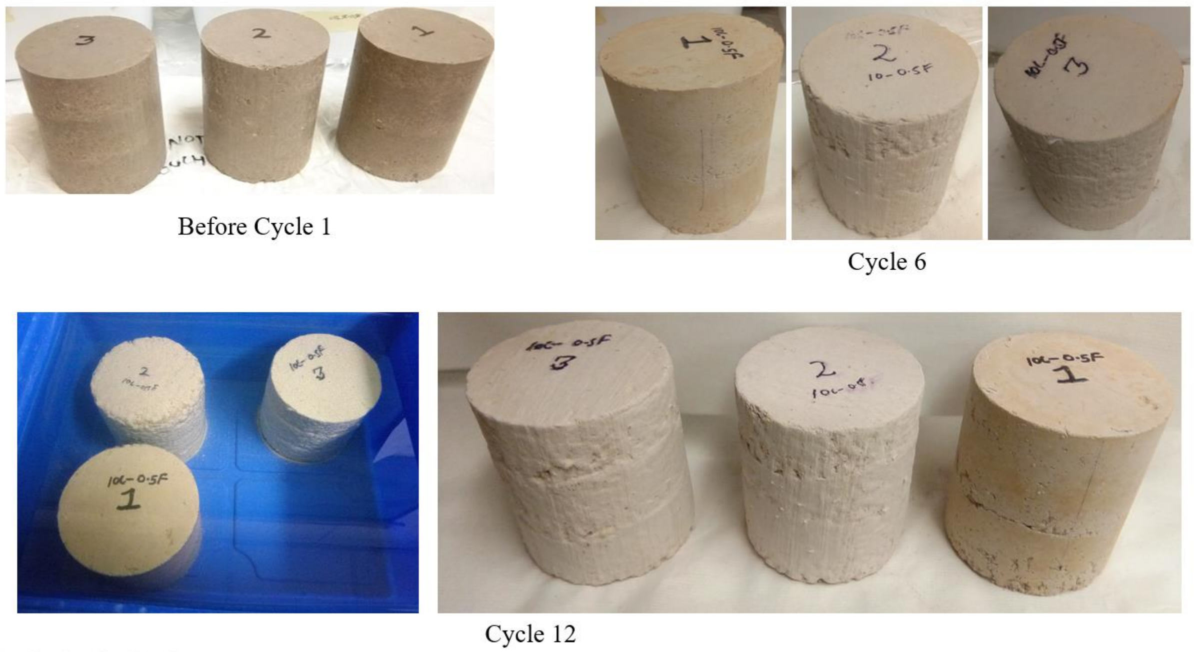


Figure 4-29: Various stage of wetting-drying test of WD_10C_0.5F

Using the same procedure used for EPK clay stabilized with 5% cement and 0.5% fiber, approximate percentage loss of soil-cement-fiber after each cycle end was calculated and shown in Figure 4-30. In this case, percentage loss of soil-cement-fiber for both unbrushed and brushed samples is less than 7% after 12th cycle. Thus, based on PCA criteria, EPK clay stabilized with 10% cement and 0.5% fiber is durable against the wetting-drying cycle.

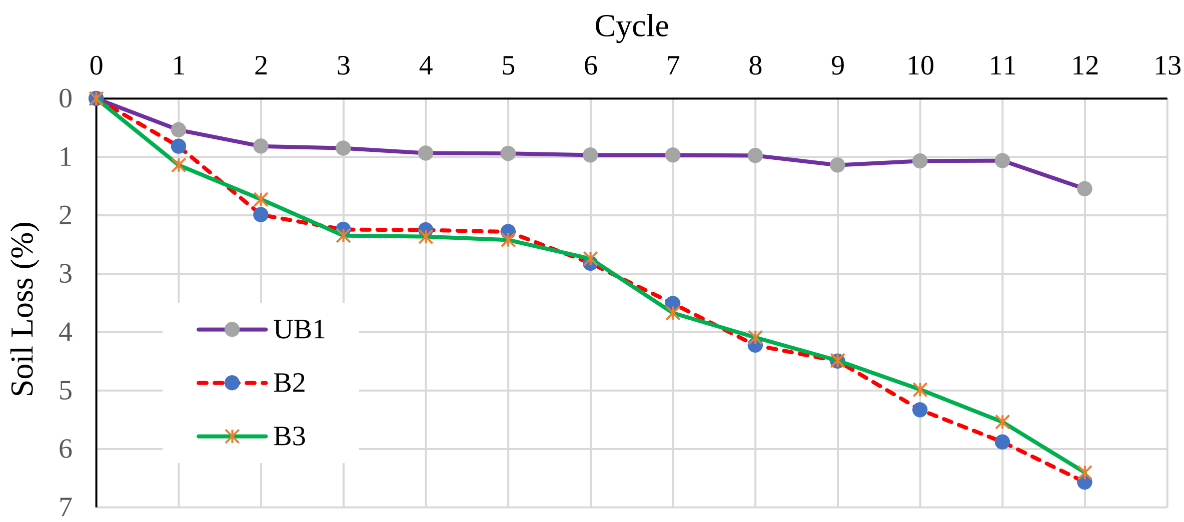


Figure 4-30: Percentage loss of stabilized soil in each cycle for WD_10C_0.5F

4.10.2 Result comparison of different combination for wetting-drying test

The overall result of the wetting-drying test for different condition is summarized in a graphical form Figure 4-31 and Figure 4-32, and in tabular form as shown in Table 4-4. From Figure 4-31, it can be observed that percentage loss of stabilized soil is less than 7% in only one combination of stabilizer. For the clay stabilized with 10% cement only and with 5% cement + 0.5% fiber, only the unbrushed sample has soil loss less than 7%. For the clay stabilized with 10% cement + 0.5% fiber, all samples survived and have soil loss less than 7%. Percentage loss of soil for brushed samples is in marginal range so we can say that 10% with 0.5% fiber is the optimum amount of stabilizer for EPK clay against wetting-drying action. Increase of cement content will be uneconomical as well as sample will be brittle. The addition of more fiber may affect the density and permeability of sample. Thus, 10% cement + 0.5% fiber is the optimum content of stabilizer for EPK clay against wetting-drying test. Further, the compressive strength of sample stabilized with 10% cement and 0.5% fiber is significantly higher as shown in Figure 4-32. Also, this combination has compressive strength significantly higher than the 28 days wet

UCS set by Highway Research Board (1961). Also, 10% cement + 0.5% fiber combination satisfied the durability criteria for wetting-drying test set by PCA and minimum cement content requirement criteria set by ACI committee and Packard (1962). USACE suggested that maximum allowable weight loss after 12 wet-dry cycles for clay should be less than 6%, and for silt should be less than 8%. Soil used for this research is Silty Clay (MH) and USACE has not specified the weight loss criteria for a particular soil type. Considering the average weight loss of clay and silt requirement, this combination also fulfills the maximum allowable weight loss criteria of USACE durability requirement. The cement content requirement for durability test as per ACI committee for A-7 type of soil is between 10-16%. Packard (1962) also suggested that minimum cement content for wetting-drying test should be at least 5%. The combination used for this research has 10% cement along with 0.5% fiber, thus it fulfills the cement requirement criteria set by ACI committee and Packard (1962).

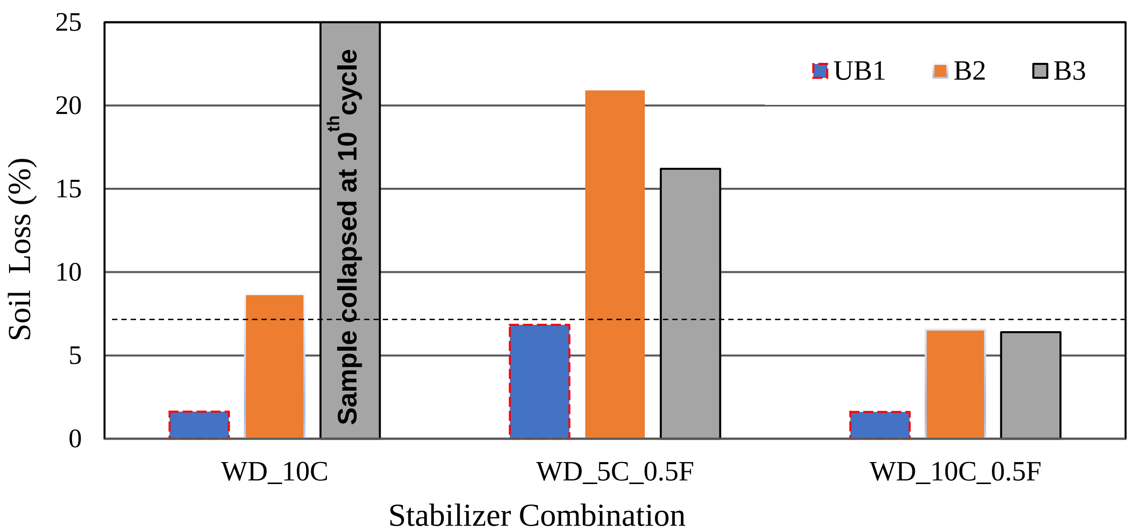


Figure 4-31: Percentage of soil loss during wetting-drying test for different combination

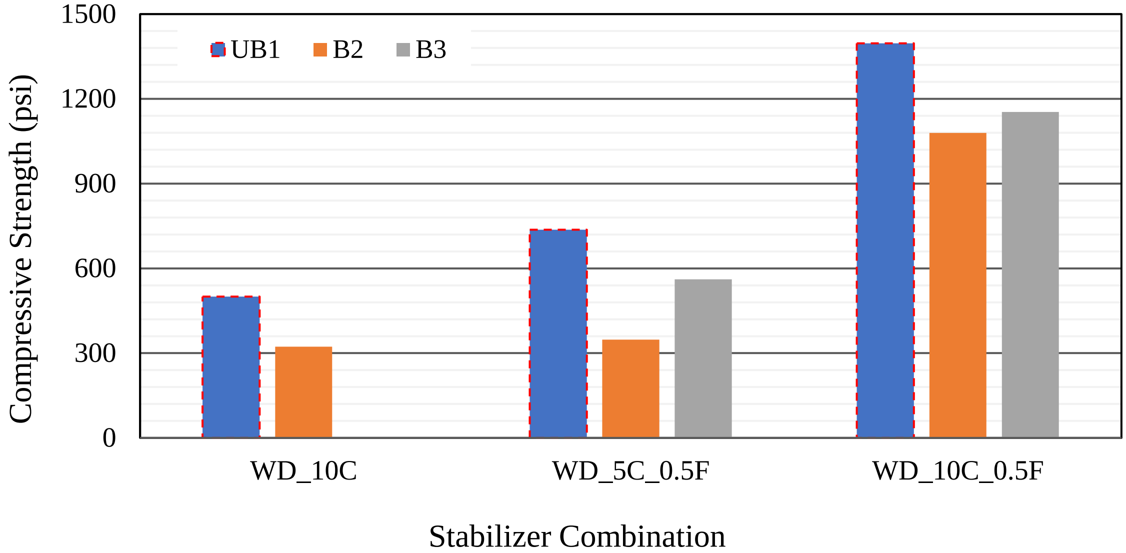


Figure 4-32: Compressive strength after wetting-drying test for different combination

Table 4-4: Summary of wetting-drying test results

Sample Details	Test Sample	Soil Loss (%)	Compressive Strength (psi)	Remarks	Durability Result
EPK Clay	**Unbrushed**	-	-	Collapsed in 2nd cycle	Not Durable against WD
	Brushed				
	-Sample 2	-	-	Collapsed in 2nd cycle	
	-Sample 3	-	-	Collapsed in 2nd cycle	
EPK+5% Cement	**Unbrushed**	16.06	-	Stopped at 4th cycle	Not Durable against WD
	Brushed				
	-Sample 2	-	-	Collapsed in 4th cycle	
	-Sample 3	26.67	-	Stopped at 4th cycle	
EPK+10% Cement	**Unbrushed**	1.63	500.08	Completed all cycle	Not Durable against WD
	Brushed				
	-Sample 2	8.68	322.84	Completed all cycle	
	-Sample 3	-	-	Collapsed in 10th cycle	
EPK+5% Cement+0.5%fiber	**Unbrushed**	6.84	737.1544	Completed all cycle	Survived all 12 cycle but fail to meet durability criteria
	Brushed				
	-Sample 2	20.89	347.70	Completed all cycle	
	-Sample 3	16.20	561.37	Completed all cycle	
EPK+10% Cement+0.5%fiber	**Unbrushed**	1.61	1396.42	Completed all cycle	Durable against WD, all sample meet durability criteria and high CS
	Brushed				
	-Sample 2	6.55	1079.69	Completed all cycle	
	-Sample 3	6.39	1153.44	Completed all cycle	

4.10.3 Freezing-Thawing Test

4.10.3.a EPK clay (FT_0C)

Three standard Proctor samples of EPK clay were subjected to freezing-thawing test. Similar to wetting-drying test, Sample 1 was unbrushed, and Sample 2 and Sample 3 were brushed. The percentage loss of soil at the end of first and second cycle was significantly higher and all the samples collapsed completely during third cycle as shown in Figure 4-33. Volume change of unbrushed sample is shown in Figure 4-34. As the sample collapsed completely, percentage loss of soil and compressive strength of test sample cannot be found. Thus, EPK clay (with no cement and fiber) was not durable against freezing-thawing action. Five percent cement was added on EPK clay and again freezing-thawing durability test was carried out.

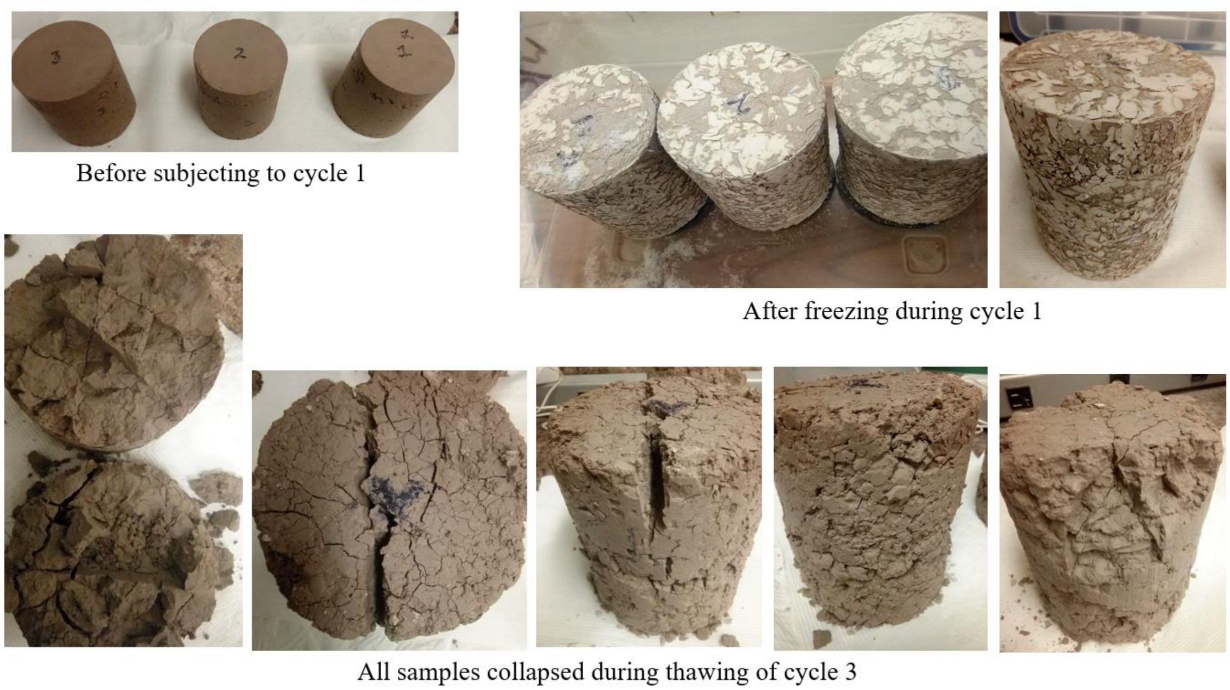


Figure 4-33: Freezing-Thawing effect on EPK clay (FT_0C)

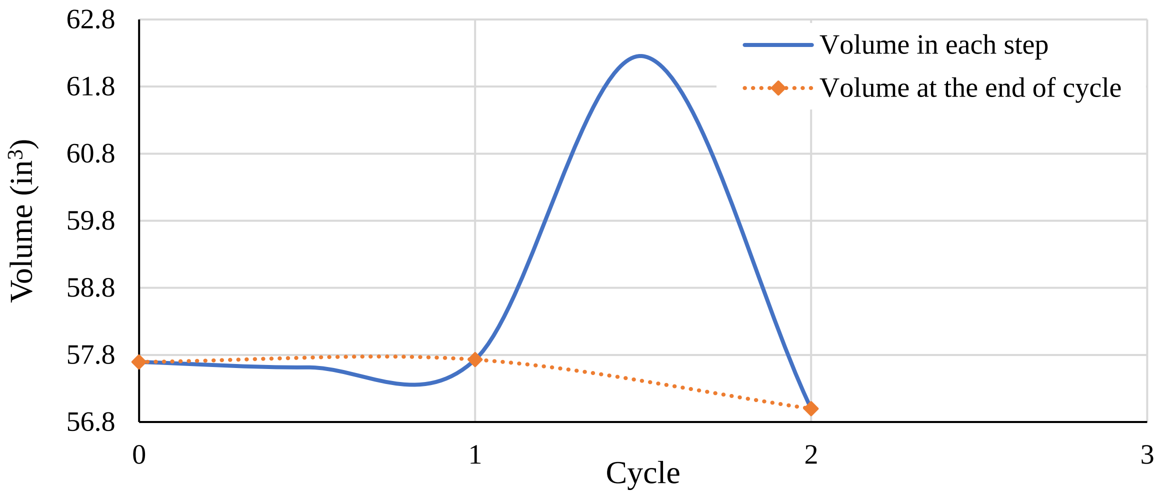


Figure 4-34: Volume change with cycle for FT_0C (UB1)

4.10.3.b EPK clay stabilized with 5% Cement (FT_5C)

With the addition of 5% cement, Sample 1 and Sample 3 collapsed in 3rd cycle, and Sample 2 was stopped after 4th cycle. Due to heavy deterioration of samples, compressive strength test of Sample 2 was not carried out. The percentage loss of soil for unbrushed Sample 2 was 19.4% after 4th cycle. This result confirms that EPK clay stabilized with only 5% cement was not durable against freezing-thawing test. Figure 4-35 shows the deterioration condition at various stage of durability test. Figure 4-36 shows the volume of unbrushed sample during the freezing-thawing test. The increase in volume was due to freezing action which leads to the collapse of samples.

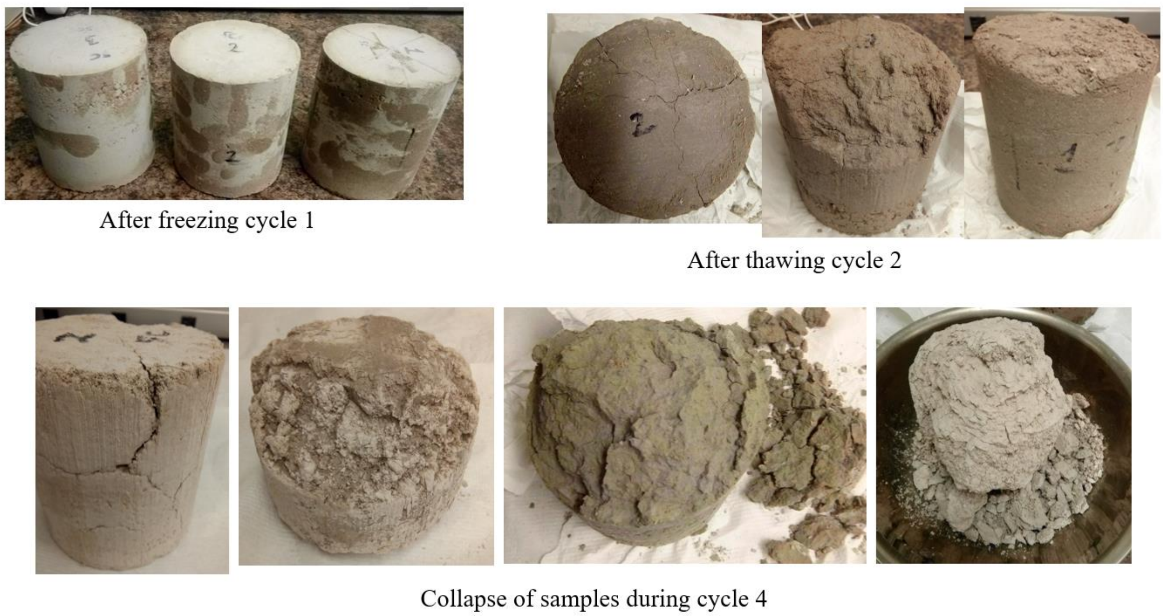


Figure 4-35: Various stage of freezing-thawing test of FT_5C

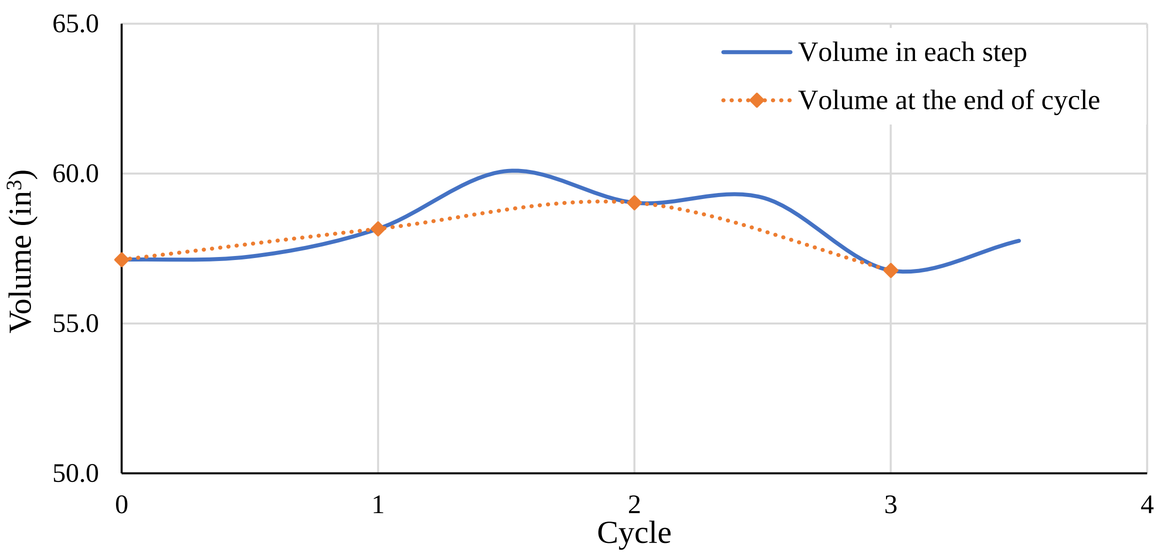


Figure 4-36: Volume change with cycle for FT_5C (UB1)

4.10.3.c EPK clay stabilized with 10% Cement (FT_10C)

Cement content was increased to 10% and freezing-thawing test was conducted. With the increase in cement content, all the samples survived up to 12 cycles of weathering action against freezing-thawing test. Percentage loss of soil for Sample 1, Sample 2 and Sample 3 was 0%, 6.94%, and 8.79%, respectively. No any percent loss of soil for unbrushed samples while marginal loss of soil loss for the brushed sample. Compressive strength of oven-dried samples at the end of freezing-thawing cycles for Sample 1, Sample 2 and Sample 3 was 398.44 psi, 400.72 psi, and 263.02 psi, respectively. Figure 4-37 shows the mass of all three samples after each cycle ends. Figure 4-38 shows the volume of unbrushed sample during wetting-drying test. Figure 4-39 shows the deterioration condition at various stage of durability test for EPK clay sample stabilized with 10% cement. All the three samples survived up to 12 weathering cycle and have percent loss of soil less than 7%.

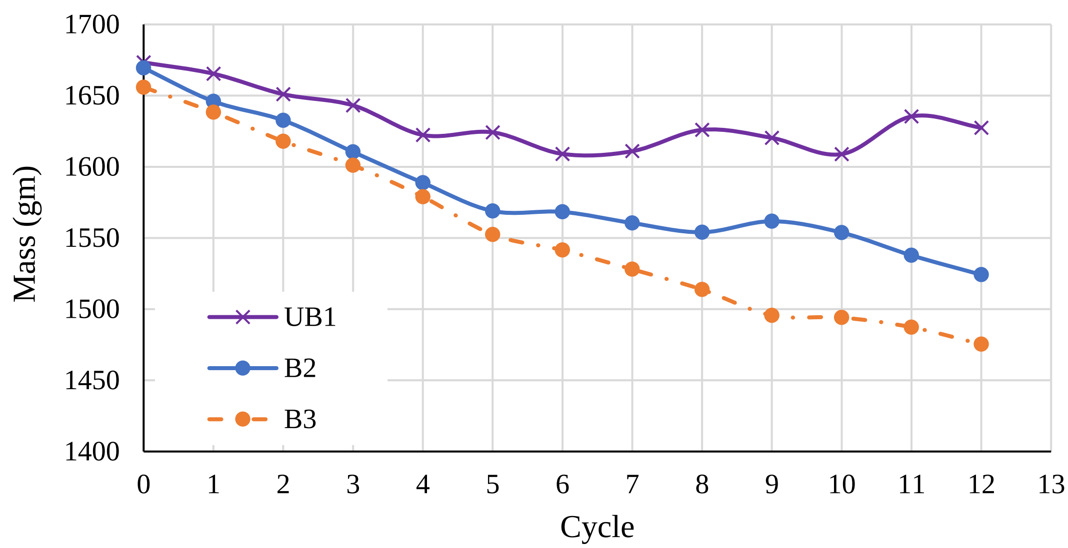


Figure 4-37: Mass change with cycle for FT_10C

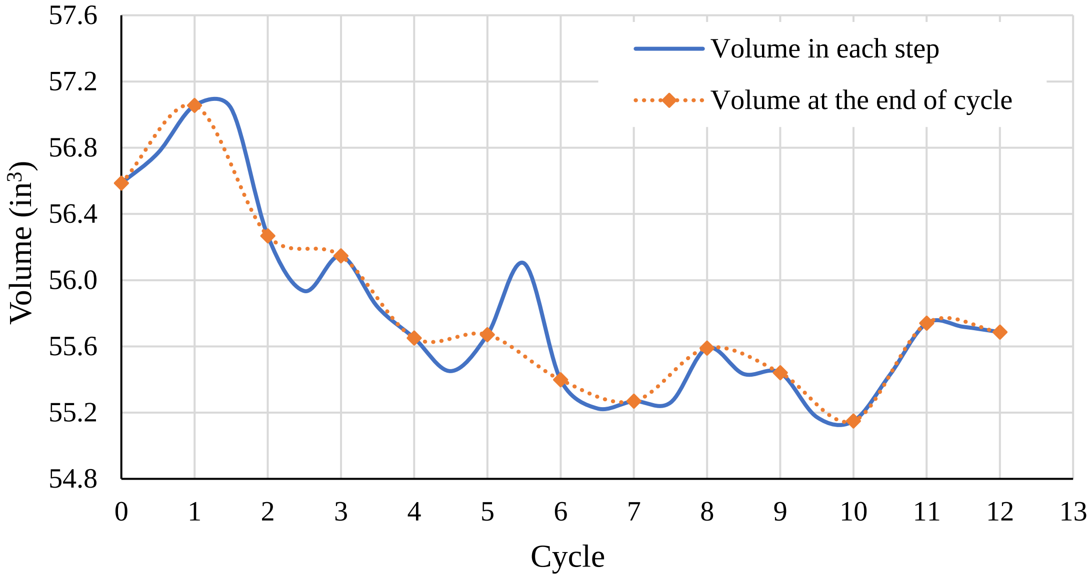


Figure 4-38: Volume change with cycle for FT_10C (UB1)

Cycle 3

Cycle 6

After oven dried (end of cycle)

Figure 4-39: Various stage of freezing-thawing test of FT_10C

Using the concept of PCA moisture content estimation method and backward calculation referencing the oven-dried mass after 12th cycle as standard, the approximate percentage loss of stabilized soil was calculated and shown in Figure 4-40.There was no soil loss in unbrushed sample. Result shows that EPK clay stabilized with 10% cement was durable against the freezing-thawing test.

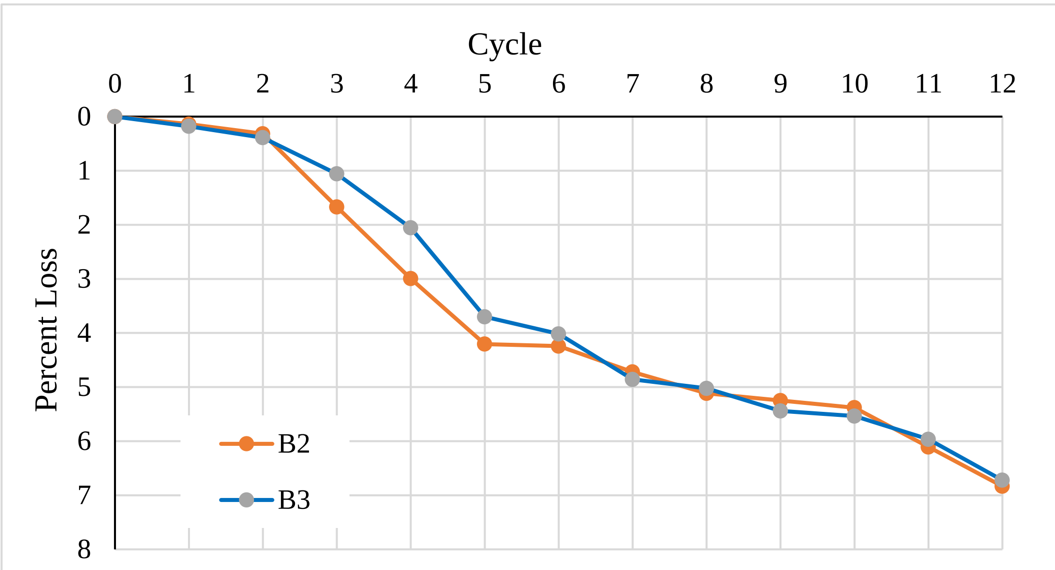


Figure 4-40: Percentage loss of stabilized soil in each cycle for FT_10C

4.10.3.d EPK clay stabilized with 5% Cement and 0.5% Fiber (FT_5C_0.5F)

To increase the tensile strength and durability against freezing-thawing, cement stabilized samples were reinforced with a small percentage of fiber. Addition of fiber results in the survivable of all three samples up to 12 cycles of weathering action. Percentage loss of stabilized soil-cement-fiber of Sample 1 was 1.99%, Sample 2 was 6.5% and Sample 3 was 6.5%. Compressive strength of oven dried samples after 12th wetting-drying cycle for Sample 1, Sample 2 and Sample 3 was 455.5 psi, 462.4 psi, and 509.92 psi, respectively. Figure 4-41 shows the mass of all three samples after each cycle ends. Figure 4-42 shows the volume of unbrushed sample during wetting-drying test. Figure 4-43 shows the deterioration condition at various stage of durability test for EPK clay sample stabilized with 5% cement and 0.5% fiber. All the three samples survived up to 12 weathering cycle and have percent loss less than 7%. Thus, EPK clay stabilized with 5% cement and 0.5% fiber is durable against freezing-thawing test.

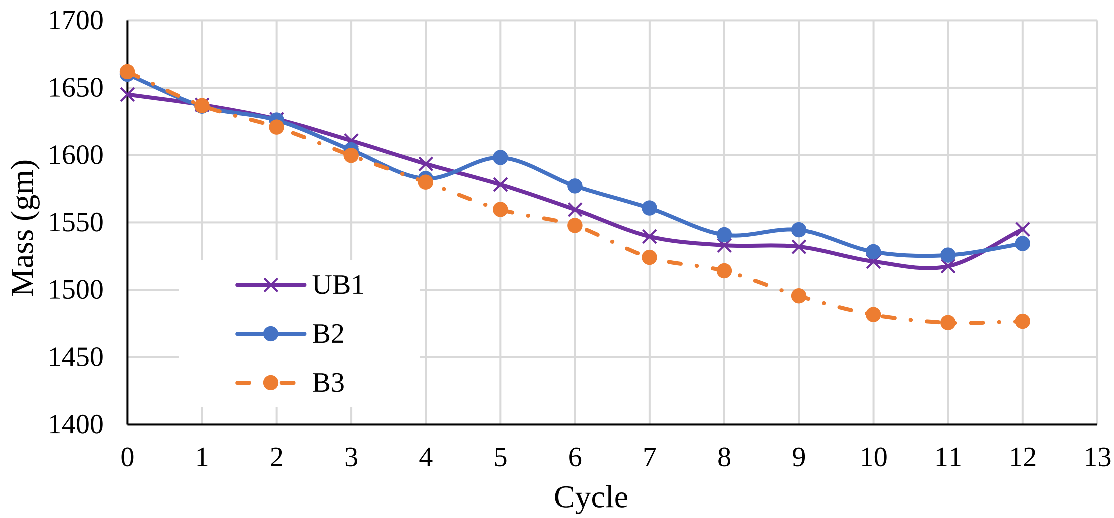


Figure 4-41: Mass change with cycle for FT_5C_0.5F

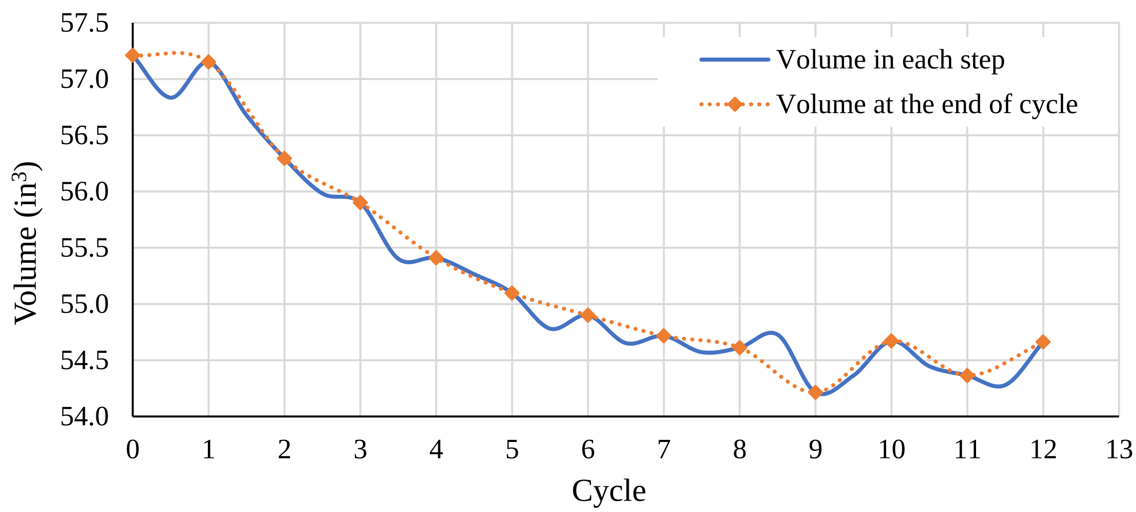


Figure 4-42: Volume change with cycle for FT_5C_0.5F (UB1)

Figure 4-43: Various stage of freezing-thawing test of FT_5C_0.5F

Using PCA approximate moisture content estimation method and backward calculation referencing the final oven-dried mass as standard, the percentage loss of soil was calculated at each cycle end, which is shown in Figure 4-44.

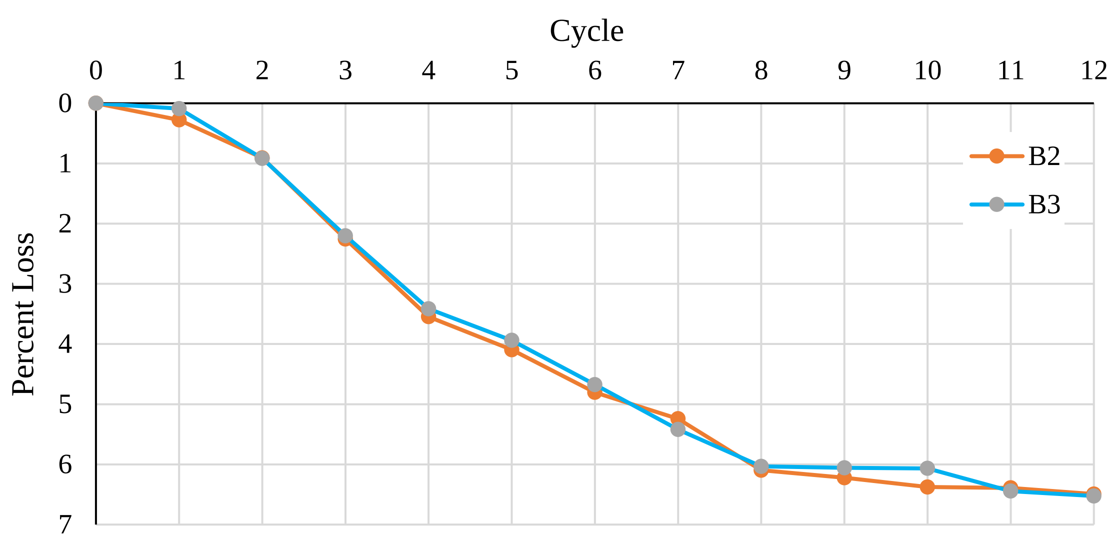


Figure 4-44: Percentage loss of stabilized soil in each cycle for FT_5C_0.5F

4.10.3.e EPK clay stabilized with 10% Cement and 0.5% Fiber (FT_10C_0.5F)

Although the EPK clay stabilized with 10% cement or 5% cement with 0.5% fiber was durable against freezing-thawing action, addition test, 10% cement + 0.5% fiber was performed to- compare the result with wetting-drying test, check the increase in compressive strength, and ductility behavior. All the samples stabilized with 10% cement and 0.5% survived up to 12 weathering cycle and very less percentage loss of soil when compared with other tests. Percentage loss of stabilized soil-cement-fiber of Sample 1 was 0%, Sample 2 was 3.81% and Sample 3 was 3.47%. Compressive strength of oven dried samples after 12th wetting-drying cycle for Sample 1, Sample 2 and Sample 3 was 502.5 psi, 541.14 psi, and 583.23 psi, respectively. Figure 4-45 shows the mass of all three samples after each cycle ends. Figure 4-46 shows the volume of unbrushed sample during wetting-drying test. Figure 4-47 shows the deterioration condition at various stage of durability test for EPK clay sample stabilized with 10% cement and 0.5% fiber. EPK clay stabilized with 10% cement and 0.5% fiber is durable against freezing-thawing test.

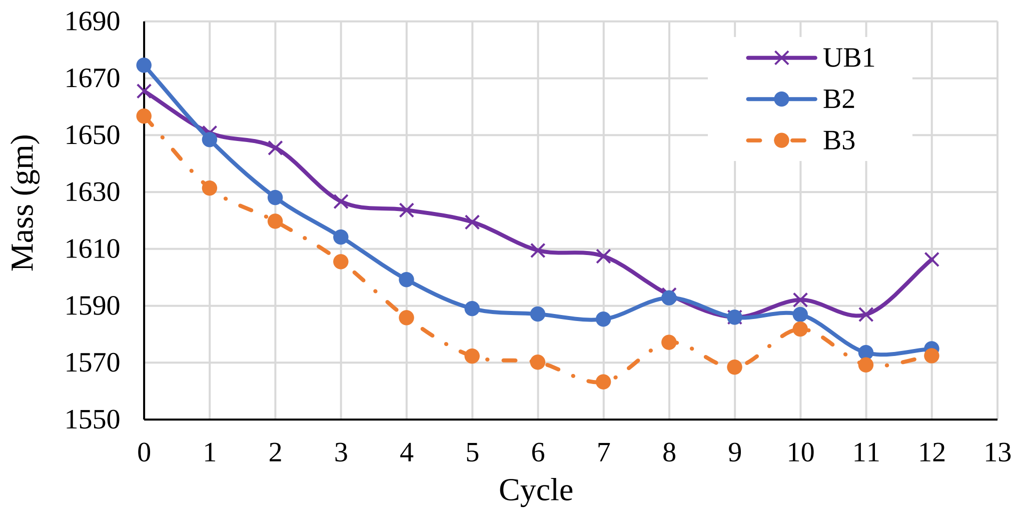


Figure 4-45: Mass change with cycle for FT_10C_0.5F

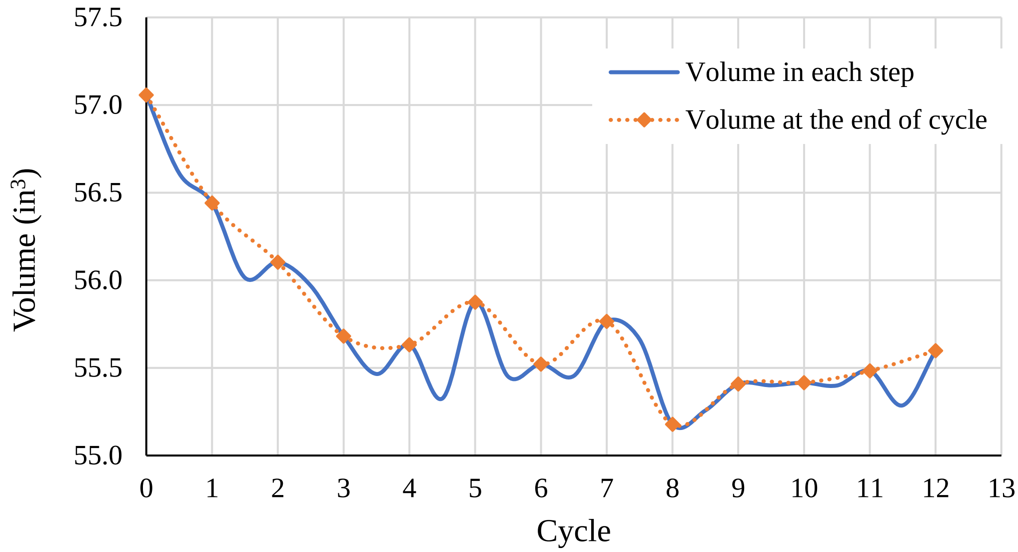


Figure 4-46: Volume change with cycle for FT_10C_0.5F (UB1)

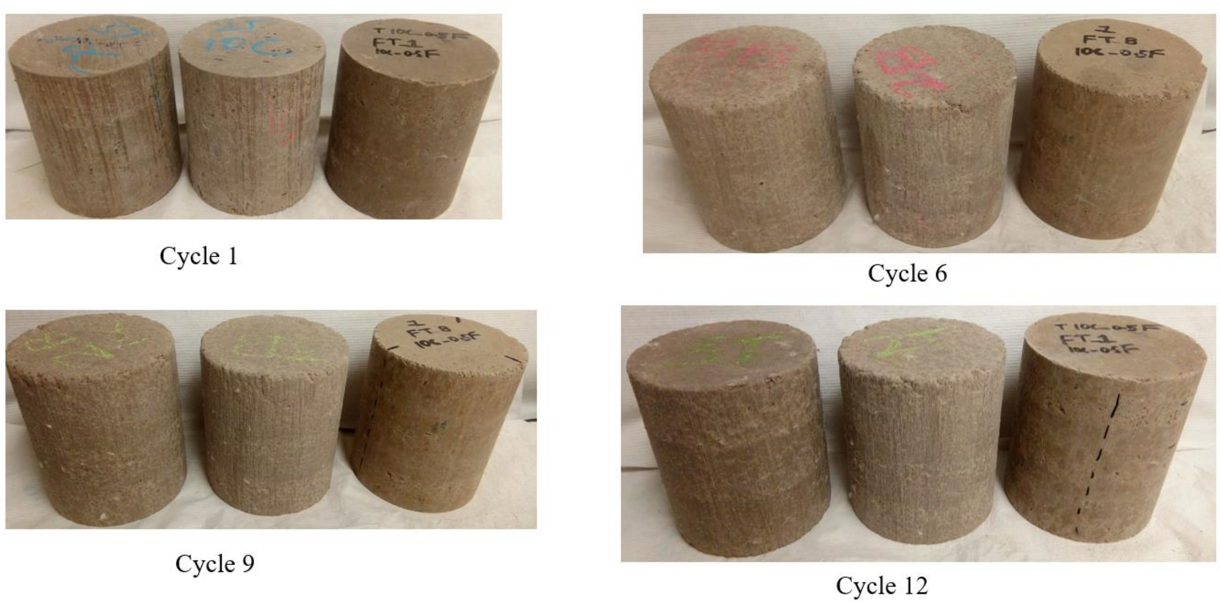


Figure 4-47: Various stage of freezing-thawing test of FT_10C_0.5F

Approximately percentage loss of soil after each cycle was estimated which is shown in Figure 4-48.

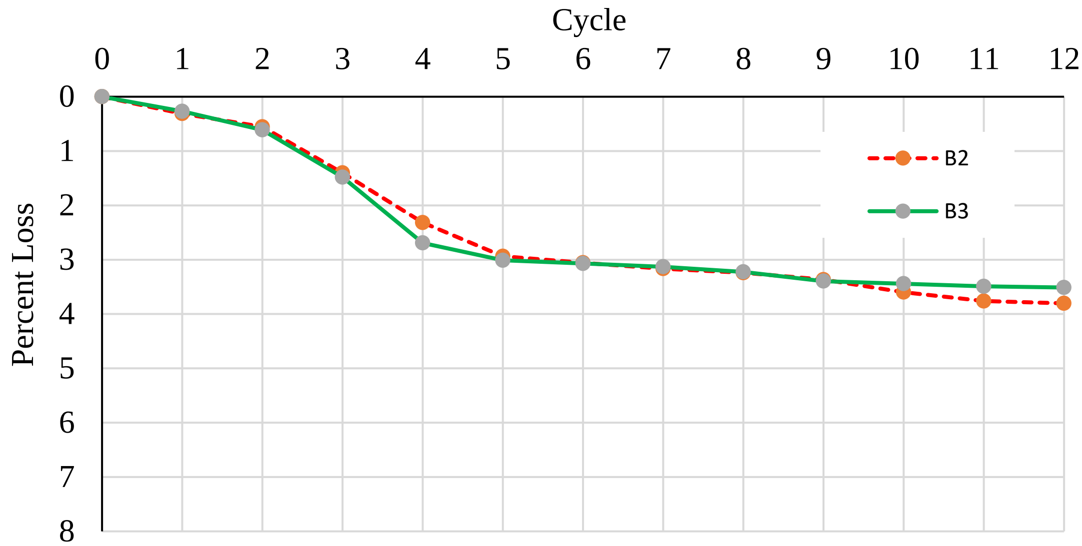


Figure 4-48: Percentage loss of stabilized soil in each cycle for FT_10C_0.5F

4.10.4 Result comparison of different combination for freezing-thawing test

The summary result of freezing-thawing test for different combination is presented in graphical form Figure 4-49 and Figure 4-50, and tabular form as shown in Table 4-5. From Figure 4-49 it can be observed that percentage loss of soil is less than 7% for three different combination- 10% cement only, 5% cement + 0.5% fiber, and 10% cement + 0.5% fiber. For the combination with 10% cement, percent loss of soil for unbrushed sample was 0%. Percent loss of soil for 10% cement only and 5% cement + 0.5% fiber was in marginal range for brushed sample while for 10% cement + 0.5% fiber, percent loss of soil is almost half than the previous two combinations of soil cement. EPK clay, and clay stabilized with 5% cement only is not durable against freezing-thawing test. From Figure 4-34 and Figure 4-36 it can be seen that there was great increase in volume during freezing action of early cycle which lead to complete collapse of samples while for other combination with cement or fiber, volume during freezing was decreased or remain constant in most of the cycles and ultimately samples survived throughout the whole weathering action.

According to Highway Research Board (1961) range of wet UCS for cement stabilized clay soil (A-7) after 28 days is 250-600 psi. Similar range of compressive strength was observed in the present study after the end of the cycle, after 12th cycle of freezing-thawing, compressive strength for survived sample range from 263 psi to 583 psi. Maximum allowable weight loss after 6 freezing-thawing cycles proposed by USACE was 6%. In this research, the percent loss of soil after 12 cycles of freezing-thawing was less than 7% for clay stabilized with 10% cement, 5% cement + 0.5% fiber and 10% cement + 0.5% fiber. From Figure 4-40, Figure 4-44 and Figure 4-48 it can be observed that percent loss of soil after 6 freeze-thaw cycle was less than 4.8% for all. Thus, all three combinations fulfill the durability criteria of percent loss set by both PCA and USACE. Cement content required for stabilization proposed by USACE and Packard (1962) is 10%. In addition, ACI committee also suggested a range of cement content was 10% to 16% for the durability of stabilized clay (A-7 type of soil). This research also finds the exactly similar result, when cement only was used for stabilization, 10% cement of dry wet of soil was required for the durability of stabilized soil. In addition to cement, 0.5% fiber was used to check the durability and found that 5% cement + 0.5% fiber also provide the durability of stabilized clay against freezing-thawing. Soil stabilization with 10% cement or 10% cement + 0.5% fiber may be uneconomical and results in the brittle failure pattern due to higher cement content. Thus, 5% cement + 0.5% is suggested as the optimum content of stabilizer for durability against the freezing-thawing test.

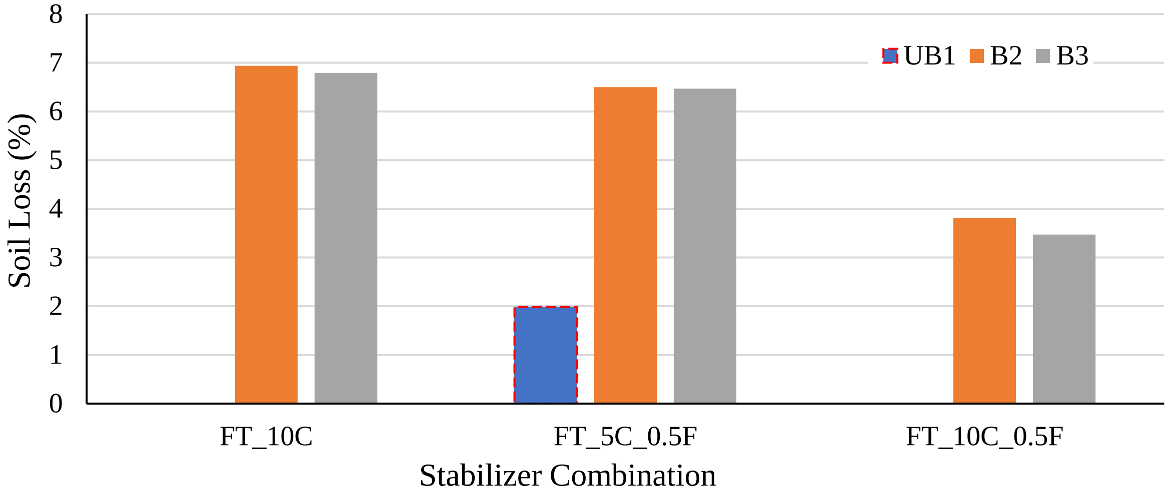


Figure 4-49: Percentage soil loss during freezing-thawing test for different combination

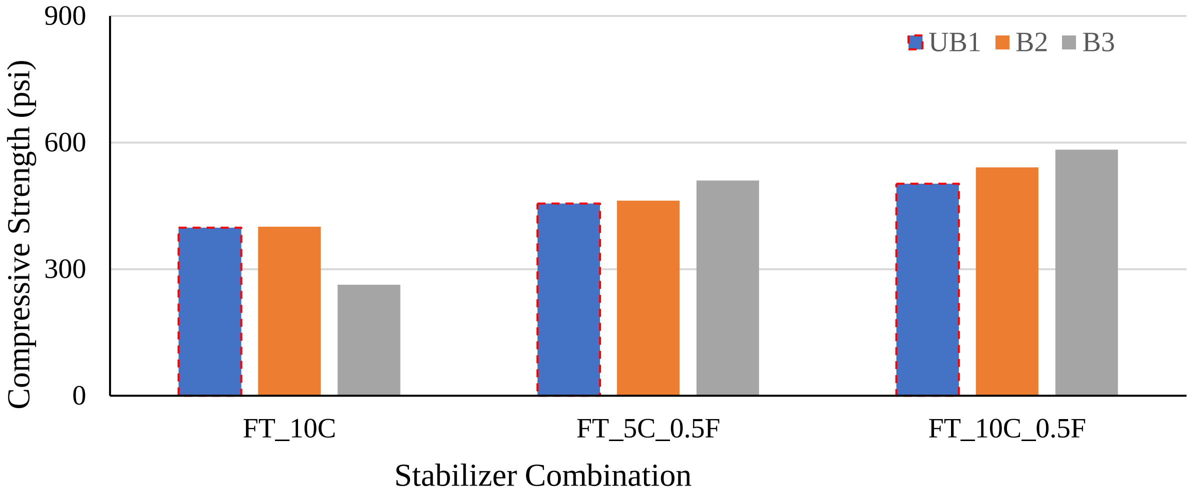


Figure 4-50: Compressive strength after freezing-thawing test for different combination

Table 4-5: Summary of freezing-thawing test results

Sample Details	Test Sample	Soil Loss (%)	Compressive strength (psi)	Remarks	Durability Result
EPK Clay	**Unbrushed**	-	-	Collapsed in 3rd cycle	Not Durable
	Brushed				
	-Sample 2	-	-	Collapsed in 3rd cycle	
	-Sample 3	-	-	Collapsed in 3rd cycle	
EPK+5% Cement	**Unbrushed**	-	-	Collapsed 4th cycle	Not Durable
	Brushed				
	-Sample 2	19.442	-	Stopped at 4th cycle	
	-Sample 3	-	-	Collapsed in 3rd cycle	
EPK+10% Cement	**Unbrushed**	0.000	398.44	Completed all cycle	Durable against F-T and all sample meet durability criteria
	Brushed				
	-Sample 2	6.939	400.72	Completed all cycle	
	-Sample 3	6.793	263.02	Completed all cycle	
EPK+5% Cement+0.5%fiber	**Unbrushed**	1.987	455.52	Completed all cycle	Durable against F-T and all sample meet durability criteria and high CS
	Brushed				
	-Sample 2	6.501	462.41	Completed all cycle	
	-Sample 3	6.467	509.92	Completed all cycle	
EPK+10% Cement+0.5%fiber	**Unbrushed**	0.000	502.51	Completed all cycle	Durable against F-T and all sample meet durability criteria and high CS
	Brushed				
	-Sample 2	3.808	541.14	Completed all cycle	
	-Sample 3	3.472	583.23	Completed all cycle	

4.10.5 Comparison of Wetting-Drying Test and Freezing-Thawing Test

Samples without any cement content and with 5% cement content collapsed completely during the early weathering cycle of both wetting-drying and freezing-thawing durability test. So, their comparison based on soil loss percentage and compressive strength was not done. Result of wetting-drying test and freezing-thawing test for those samples which survived all cycles was plotted in same graph and comparison was made.

4.10.5.a Clay stabilized with 10% cement

For the EPK clay stabilized with 10% cement, both the durability test- wetting-drying and freezing-thawing was conducted. The result shows that clay stabilized with 10% cement was not durable against wetting-drying test but durable against freezing-thawing test as shown in Figure 4-51. In wetting-drying test, one sample collapsed before the complete cycle and another brushed sample has soil loss higher than 7%. On the other hand, for freezing-thawing test, all samples survived all weathering cycles and have soil loss of less than 7%. There is not much significant difference in compressive strength of samples subjected to wetting-drying and freezing-thawing test as shown in Figure 4-52. Figure 4-53 shows the estimated soil-cement loss percentage of brushed samples after each cycle for both wetting-drying and freezing-thawing test. For both the samples, soil-cement loss is higher at the end of cycle in wetting-drying test when compared to freezing-thawing test.

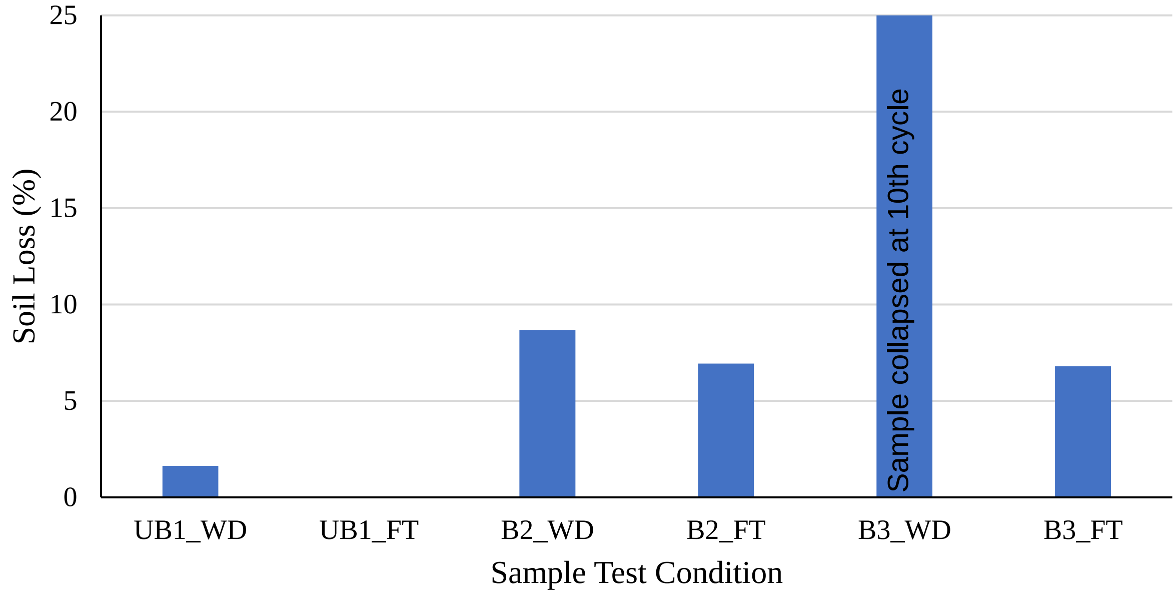


Figure 4-51: Soil loss for clay stabilized with 10% cement

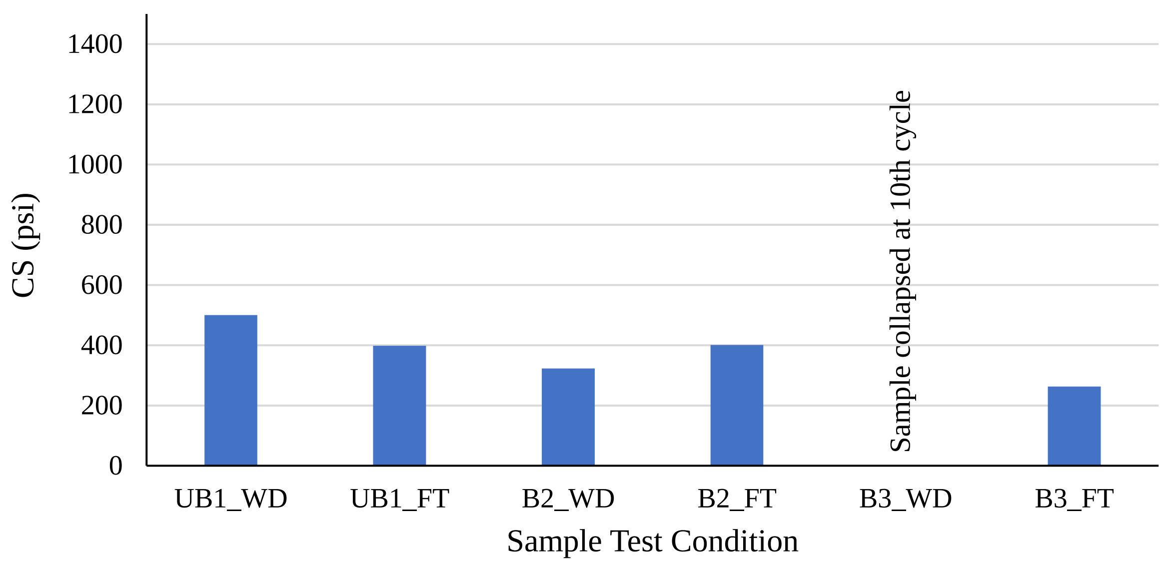


Figure 4-52: Compressive strength (CS) for clay stabilized with 10% cement

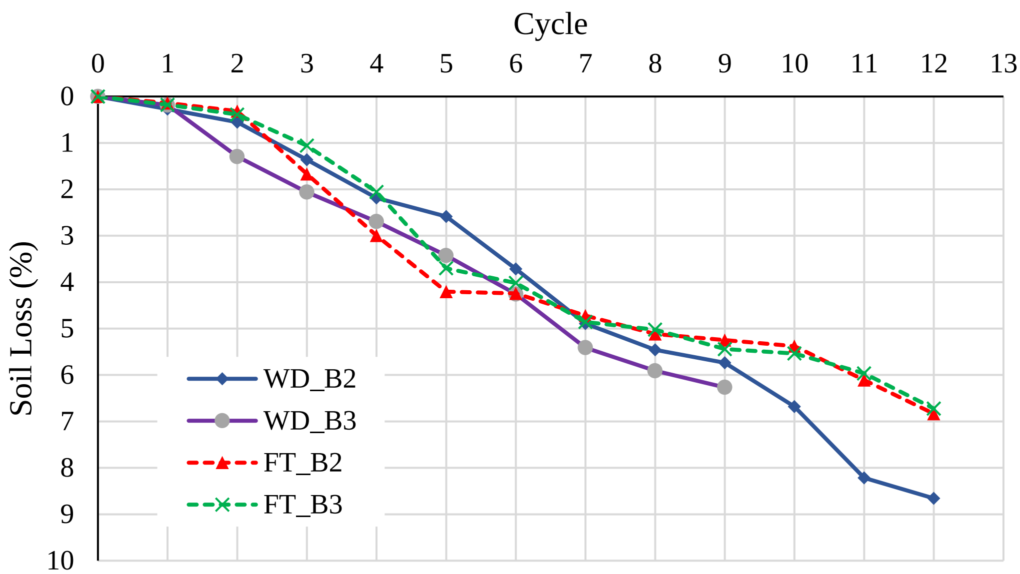


Figure 4-53: Durability test result for clay stabilized with 10% cement

4.10.5.b Clay stabilized with 5% cement and 0.5% fiber

Result of wetting-drying and freezing-thawing indicate that clay stabilized with 5% cement and 0.5% fiber survived all the weathering cycles, but the samples are durable against freezing-thawing action only. Figure 4-54 shows the percentage of soil loss for both wetting-drying and freezing-thawing in same plot. There was no significant difference in compressive strength of samples subjected to wetting-drying and freezing-thawing test Figure 4-55, all the samples have compressive strength in same range. Figure 4-56 shows the estimated soil-cement loss percentage of brushed samples after each cycle for both wetting-drying and freezing-thawing test. For both the samples, soil-cement loss is higher from the beginning of cycle in wetting-drying test when compared to freezing-thawing test. Percent soil loss in freezing-thawing test is almost half than the loss in wetting-drying test.

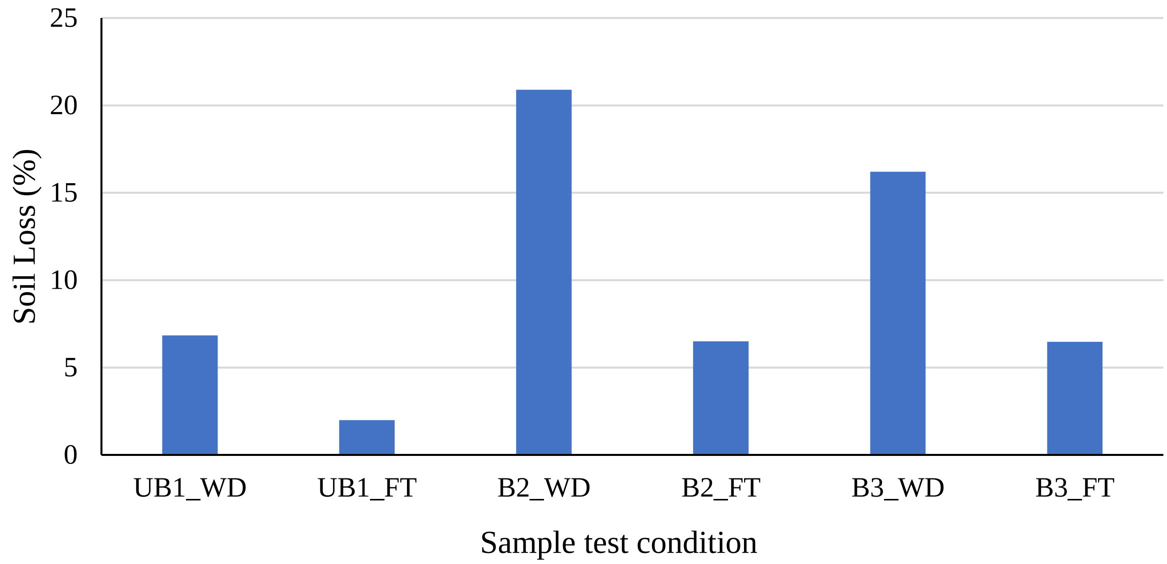


Figure 4-54: Soil loss for clay stabilized with 5% cement and 0.5% fiber

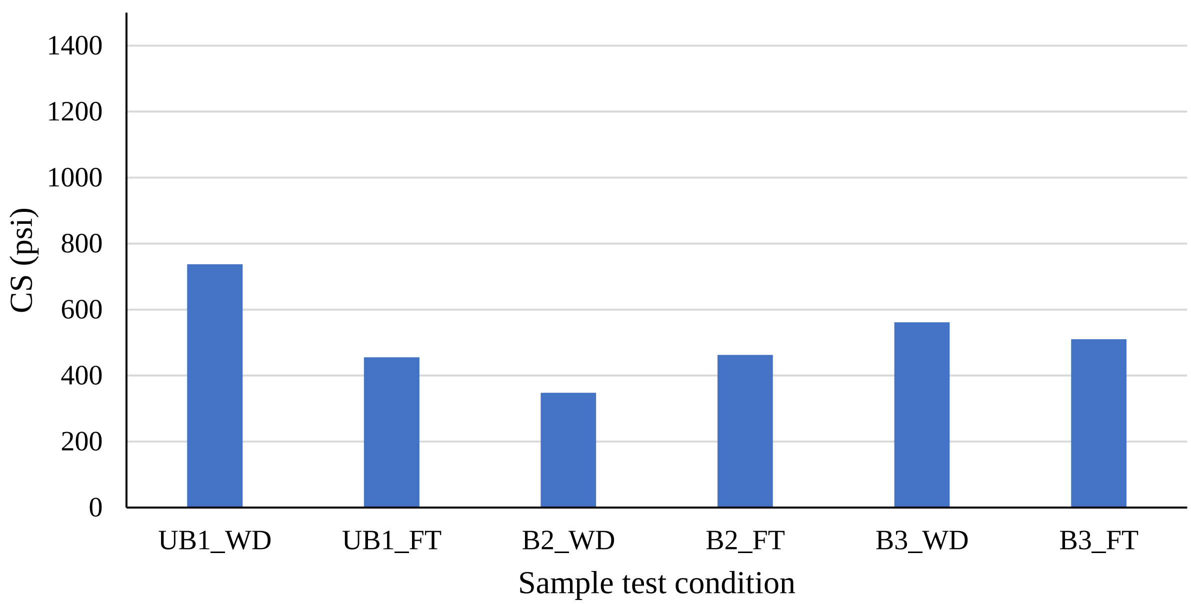


Figure 4-55: Compressive strength for clay stabilized with 5% cement and 0.5% fiber

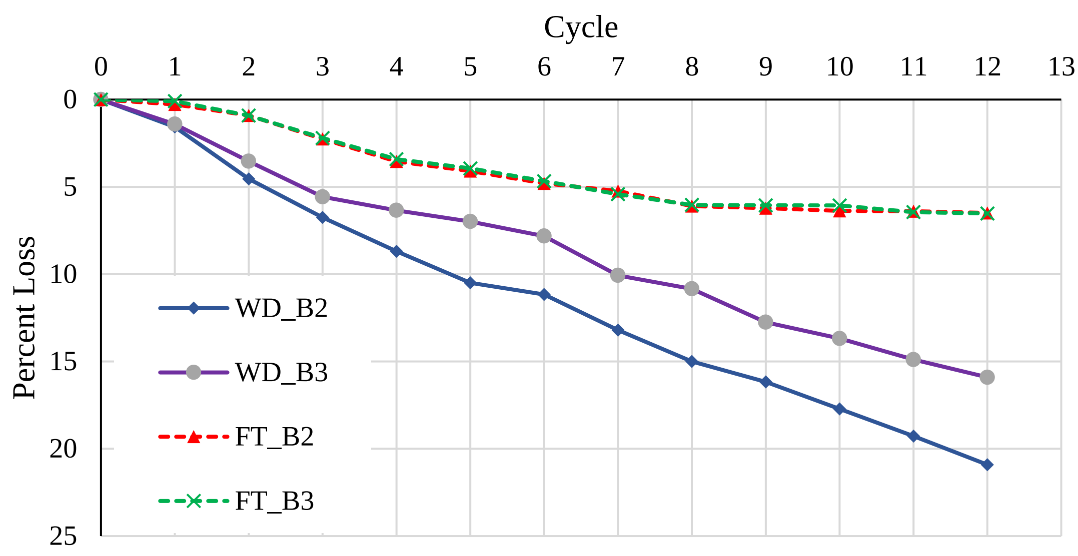


Figure 4-56: Durability test result for clay stabilized with 5% cement and 0.5% fiber

4.10.5.c Clay stabilized with 10% cement and 0.5% fiber

EPK clay stabilized with 10% cement and 0.5% fiber is durable against both weathering action- wetting-drying and freezing-thawing test. Figure 4-57 shows the percentage of soil loss during the durability test which indicates that all the samples have soil-cement loss percentage less than 7%. Soil loss percentage in wetting-drying test in marginal range whereas soil loss percentage in freezing-thawing test is almost half of the value of wetting-drying test. In this test condition, there is a significant difference in compressive strength of samples subjected to wetting-drying and freezing-thawing test as shown in Figure 4-58. Samples subjected to wetting-drying test have significantly higher compressive strength compared to freezing-thawing test. Compressive strength of wetting-drying cycle is greater than 1050 psi while the compressive strength of freezing-thawing sample is less than 600 psi. Figure 4-59 shows the estimated soil-cement loss percentage of brushed samples after each cycle for both wetting-drying and freezing-thawing test. For both the samples, soil-cement loss is higher towards the end of cycle in wetting-drying test when compared to freezing-thawing test. For the samples stabilized with 10% cement and 0.5% fiber, one interesting result has been observed. Although the soil cement loss percentage is higher in wetting-drying test, even the compressive strength is also higher for the same test. Generally, it is expected that higher the soil loss, lowers the compressive strength, but while comparing the result of wetting-drying and freezing-thawing, we get just the opposite result than our expectation. This may be due to full hydration of cement during the wetting phase, significant bond strength develops and results in the higher compressive strength of wetting-drying test.

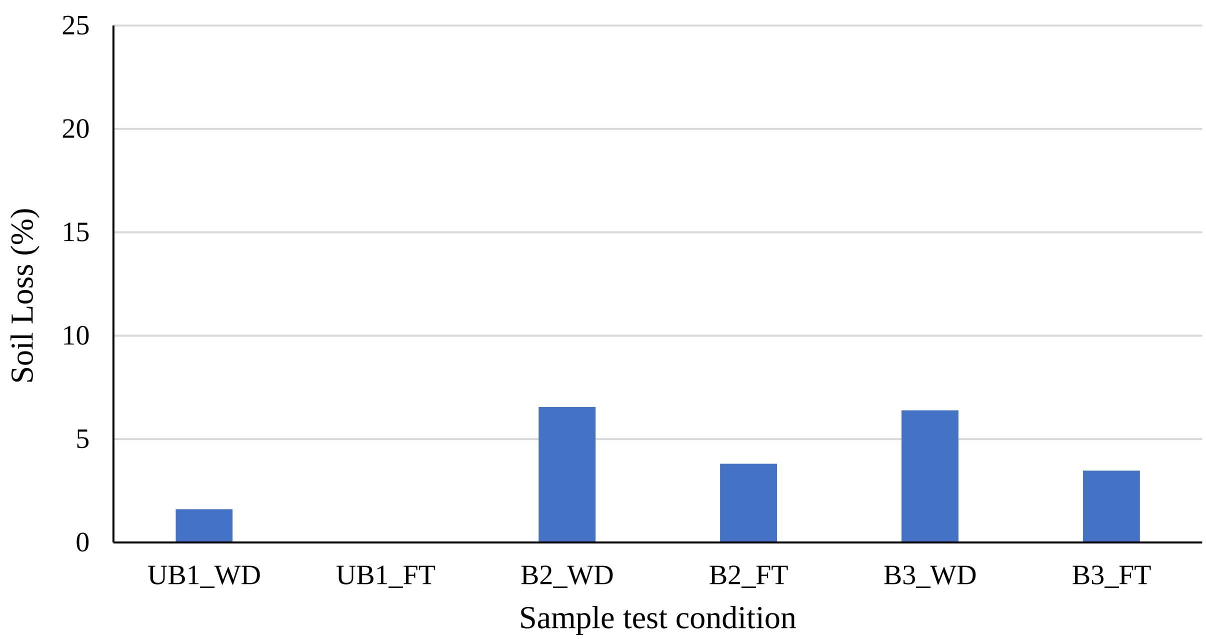


Figure 4-57: Soil loss for clay stabilized with 10% cement and 0.5% fiber

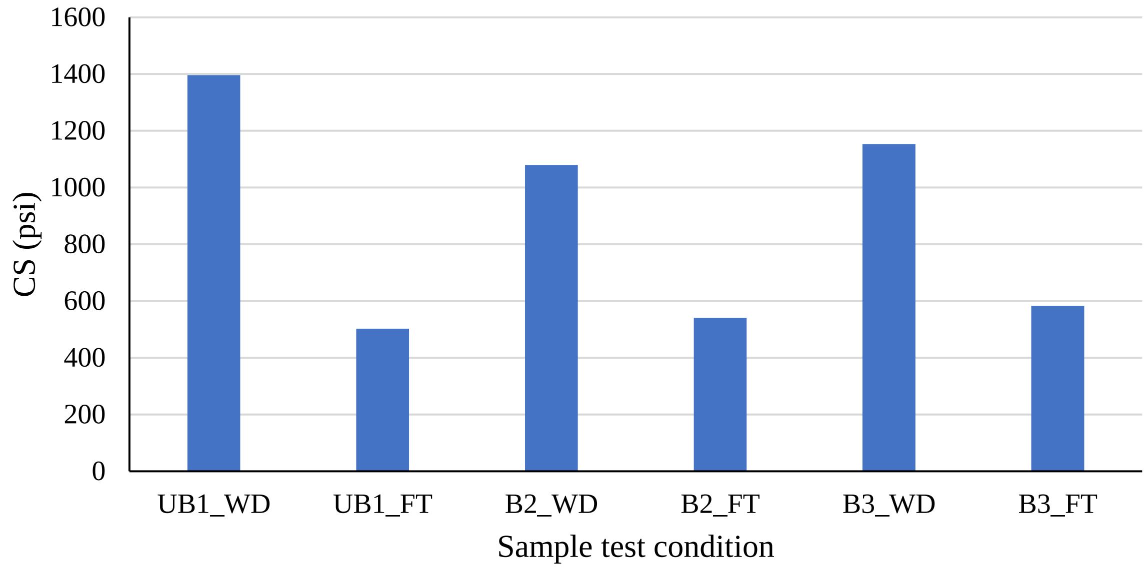


Figure 4-58: Compressive strength (CS) for clay stabilized with 10% cement and 0.5% fiber

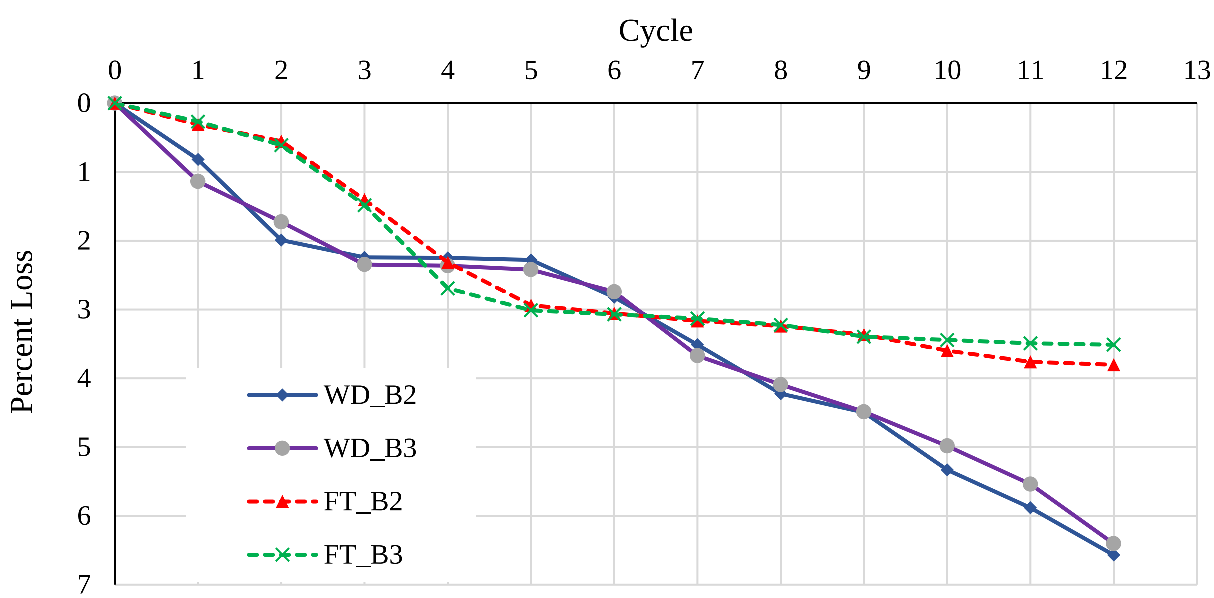


Figure 4-59: Durability test result for clay stabilized with 10% cement and 0.5% fiber

4.10.5.d Summary of comparison between wetting-drying and freezing-thawing test

Soil-cement loss percentage and compressive strength of all survived samples for both durability test are plotted in same graph as shown in Figure 4-60 and Figure 4-61, respectively. From this plot, it can be visualized the effect of different proportion of cement content on each wetting-drying and freezing-thawing test. The parameters used for analysis are soil-cement loss percentage and compressive strength after 12^{th} cycle.

From Figure 4-60, it can be observed that there was least percentage loss of soil for unbrushed samples for both durability test. Soil loss percentage for the sample stabilized with 10% cement or 10% cement + 0.5% fiber during freezing-thawing test was zero. For both wetting-drying and freezing-thawing test, sample stabilized with 10% cement + 0.5% fiber has the least value of soil-cement loss. For all the case shown in plot, percentage soil loss in freezing-thawing is less than 7% while only the samples stabilized with 10% cement + 0.5% fiber has soil loss less than 7% during wetting-drying test. From Figure 4-60, it is clear that wetting-drying test has significantly higher soil-cement loss percent for all combination of stabilizer when compared to freezing-thawing test. Based on this result we can conclude that wetting-drying durability test is more severe than freezing-thawing test for EPK clay stabilized with cement or cement-fiber combination. Theivakularatnam and Gnanendran (2015) also found that result of wetting-drying test was more heavily deterioration than freezing-thawing test for granular soil stabilized with cement and fly ash combination.

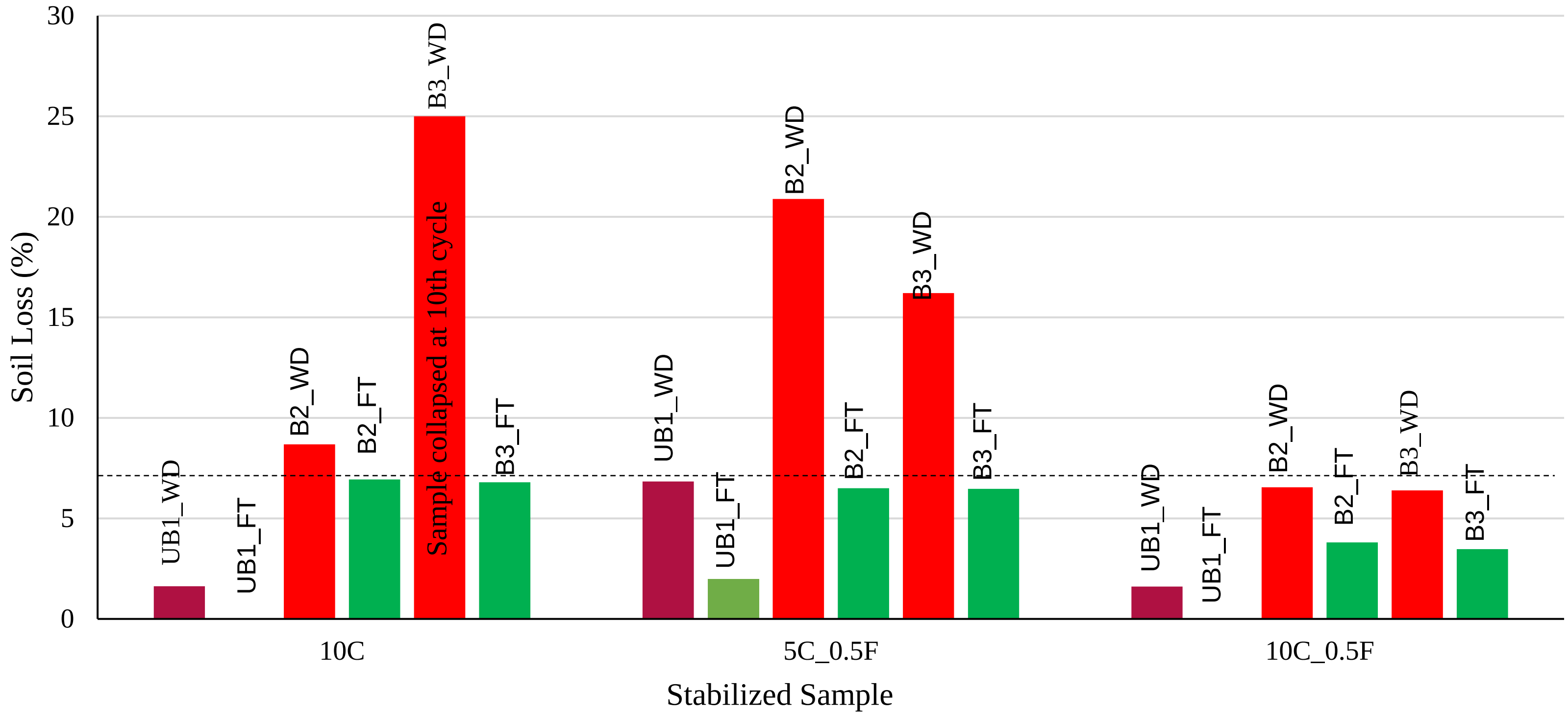


Figure 4-60: Soil loss for of all survived samples during durability test

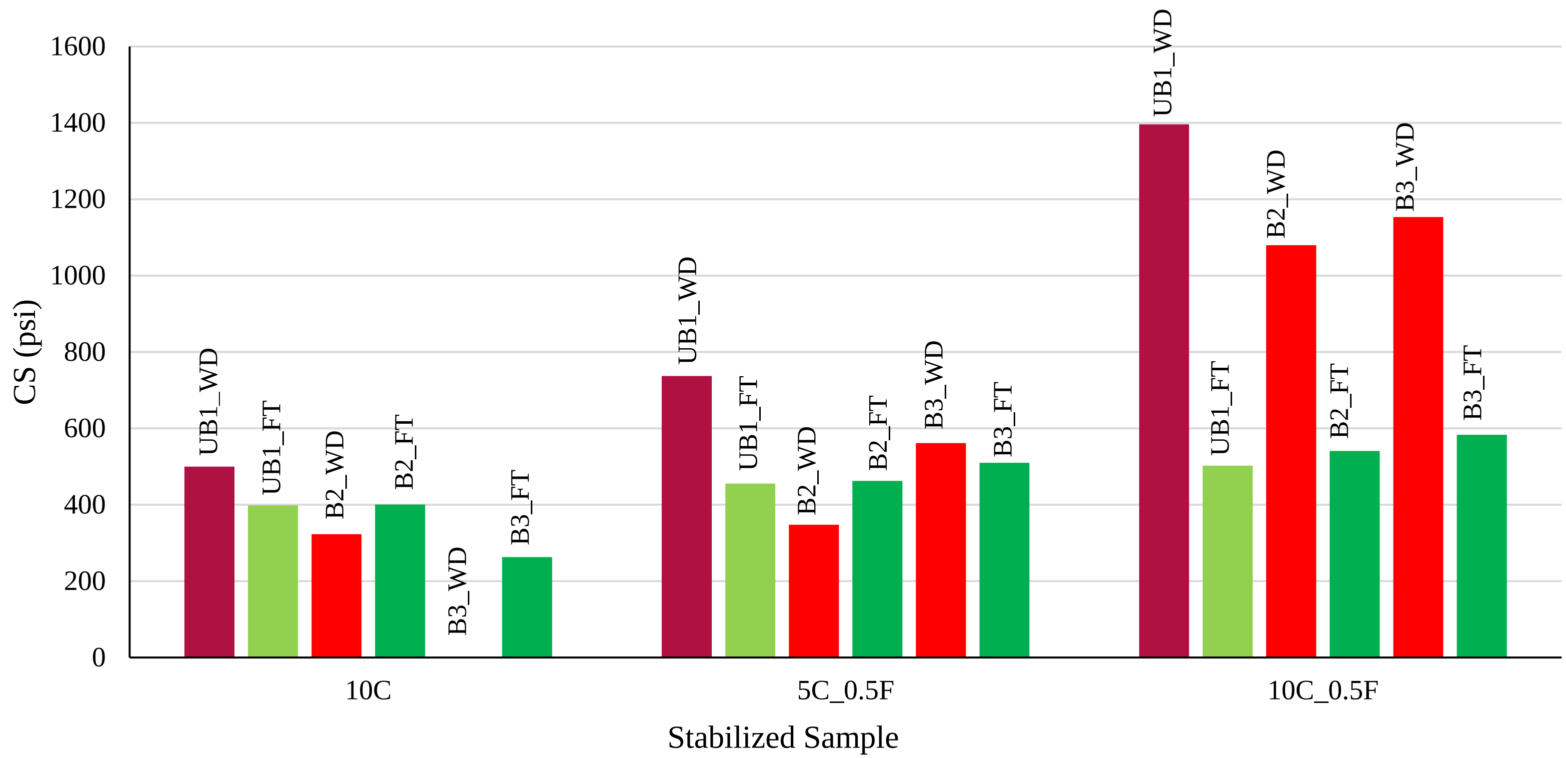


Figure 4-61: Compressive strength for of all survived samples during durability test

Figure 4-61 shows the compressive strength of all survived samples stabilized with different proportion of cement and fiber and subjected to wetting-drying and freezing-thawing test. From Figure 4-61, it can be observed that compressive strength of clay stabilized with 5% cement + 0.5% fiber was higher by a little margin only than the compressive strength of clay stabilized with 10% cement, for both freezing-thawing and wetting-drying test. For freezing-thawing test there was no significant increase in compressive strength with the addition of additional 5% cement on 5% cement + 0.5% fiber combination but for wetting-drying test compressive strength increases significantly for 10% cement + 0.5% fiber compared to 5% cement + 0.5% fiber. For 10% cement only and 5% cement + 0.5% fiber stabilization, range of compressive strength for both wetting-drying and freezing-thawing test is close. In overall, for freezing-thawing test, there was no vast differences in compressive strength for all three combinations but for wetting-dying test, compressive strength of 10% cement + 0.5% fiber was significantly higher than other two combinations, almost double.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The present research investigates the long-term durability of cement and fiber stabilized EPK clay. Before running the durability test of EPK clay, various characterization of EPK clay and EPK clay mixed with cement and fiber were conducted. Based on the laboratory setup of durability test and characterization of EPK clay, the following conclusions were drawn:

1. EPK clay is classified as High Compressible Silty Clay (MH) or A-7-5 that consists of 74% clay-sized particle and 26% silt-sized particle.
2. EPK clay has specific gravity of 2.59; when cement having specific gravity of 3.135 was added on EPK clay, overall specific gravity increases and when fiber having specific gravity of 0.93 was added, specific gravity of EPK clay decreases. The increase or decrease in specific gravity depends on the amount of cement and fiber, respectively.
3. EPK clay has the Maximum Dry Density (MDD) and minimum Optimum Moisture Content (OMC) as compared to EPK clay mixed with cement or fiber. When 5% cement content was added in EPK clay, MDD decreases, and OMC increases. Further increase in cement content results in the increase in MDD and decrease in OMC due to decrease in plasticity of soil than with 5% cement content.
4. From SEM test it can be concluded that EPK clay has flaky structure with randomly oriented conglomerated particles. Alumina and Silica are the major components of EPK clay. The addition of cement in clay adds the presence of calcium in the soil-cement mixture.

5. From the result of XRD test on EPK clay and EPK clay mixed with cement, it can be concluded that Kaolinite is the main minerals presents in EPK clay and EPK clay mixed with cement. Addition of 5% cement forms new Calcite minerals. When 10% cement was added, Calcite forms which is responsible for the durability of stabilized soil.
6. EPK clay stabilized with 10% cement + 0.5% fiber was only durable against wetting-drying test. Sample stabilized with 5% cement + 0.5% fiber survived the complete wetting-drying weathering cycle but exceed the soil-cement percent loss than specified durability criteria. Also, 10% cement + 0.5% fiber combination was the optimum content of stabilizer for durability of EPK clay against wetting-drying.
7. EPK clay stabilized with 10% cement, 5% cement + 0.5% fiber, and 10% cement + 0.5% fiber were durable against freezing-thawing combination. EPK clay stabilized with 5% cement + 0.5% cement was considered as the optimum amount for stabilizer for the durability of EPK clay against freezing-thawing.
8. Addition of fiber increases the tensile strength of sample. During the compression test, sample without fiber crumbled whereas sample with fiber cracks from many points but it didn’t crumble during the compression test. Thus, fiber improves the brittle failure pattern as well.
9. Rather than using only 10% cement for freezing-thawing test, 5% cement + 0.5% fiber may be economical and durable. Fiber improves the tensile strength and brittle failure pattern. Parsons and Milburn (2003) also suggest that combination of stabilizing agent may be economical and durable.
10. For the region with extreme cold and extreme hot temperature followed by rainfall, both wetting-drying and freezing-thawing test are recommended.

11. For EPK clay, wetting-drying test seems harsher compared to freezing-thawing test. But this may not be the case for all type of soil. Result of durability depends on the type of soil and stabilizer used. Ahmed and Ugai (2011) stabilized the sandy soil using gypsum and cement and found that the effect of freezing-thawing on stabilized sandy soil was more negative compared to wetting-drying.

5.2 Recommendations

Based on the experience after conducted the durability test of EPK clay, following recommendations have been proposed for the future research work:

1. EPK clay samples were stabilized using cement and fiber. Due to limited resources, manual mixing method was used. For more precise result, mechanical mixing method of cement and fiber in the soil is recommended. Because of manual hand mixing, some lumps of fiber were found, which can be dispersed well by using mechanical mixing method.
2. Another main and most important step that needs to be carried out for future research is humidity control. For this research, humidity chamber was made by using thick plastic ziplock tank and humidifier. But for the propose of thawing of sample during freezing-thawing, humidity and temperature control humidity chamber is strongly recommended.
3. Also, during the 7 days curing of samples, temperature and humidity control chamber is suggested.
4. If possible, brushing standardization during the wetting-drying test is suggested.
5. Percent of soil loss after each cycle was calculated based on PCA approximate method and referencing the oven dried result after 12^{th} cycle. The result obtained is very

approximate. Detail research and further experiment must be carried out for an accurate estimate of percent soil loss after each cycle.

6. Before making conclusion on the severity of test, both wetting-drying and freezing-thawing test should be conducted on various types of soil using different combination of stabilizer.
7. Due to availability of resources, only one unbrushed sample was casted for this resource. More numbers of unbrushed sample can be casted for accurate estimation of water of hydration.
8. In addition to cement and fiber, other types of stabilizer like fly ash, lime, etc. can be added and durability test can be conducted.
9. Based on literature review, 0.5% amount of fiber was used for this research, optimization of fiber using different percentage of fiber can be done. Also, different fiber length can be used to see the effect of fiber length on durability performance.
10. Unconfined Compressive Strength (UCS) can be done on same stabilized soil and their result can be correlated to the percent loss of soil-cement.

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APPENDICES

APPENDIX A

HYDROMETER TEST

Date: 08/29/2018

Specific Gravity of soil solids, Gs =	2.61	
Dry weight of soil, Wo =	50	gm
Temperature of Suspension, T =	25	˚C
Temp. correction (for 25 °C) =	1.3	
Meniscus Correction (M.C) =	1	
Specific Gravity Correction (SG.C) =	1.008	
Zero correction (Z.C) =	4	

Time (min)	**Temperature (^{0}C)**	**Hydrometer reading, R**	**Corrected Hydrometer Reading, R_{cp}**	**Corrected Hydrometer Reading for length R_{CL}**	**L (cm)**	**K**	**D (mm)**	**Percent finer**
2	25	51	49.694	52	7.766	0.0130	0.02573	99.38
5	25	51	49.694	52	7.766	0.0130	0.01627	99.38
15	25	50	48.686	51	7.930	0.0130	0.00949	97.37
30	25	48	46.670	49	8.259	0.0130	0.00685	93.34
60	25	45	43.646	46	8.751	0.0130	0.00498	87.29
250	25	41	39.614	42	9.407	0.0130	0.00253	79.22
1020	25	36	34.574	37	10.22	0.0130	0.00130	69.14
1440	25	35	33.566	36	10.39	0.0130	0.00110	67.13
2610	25	33	31.550	34	10.72	0.0130	0.00083	63.10
4155	25	32	30.542	33	10.88	0.0130	0.00066	61.08
6720	25	31	29.534	32	11.04	0.0130	0.0005	59.06

APPENDIX B

ATTERBERG LIMIT TEST

Date: 28/08/2018

Soil Type: EPK

		Weight in gm					
	Can #	Can	Can + Wet	Can + Dry	Dry Weight	MC (%)	Drops (N)
Liquid Limit Test	LL1	11.223	18.552	15.718	4.495	63.048	11
	LL2	10.922	19.983	16.507	5.585	62.238	12
	LL3	11.149	18.200	15.536	4.387	60.725	16
	LL4	10.942	19.218	16.143	5.201	59.123	22
	LL5	11.291	22.524	18.396	7.105	58.100	26
	LL6	11.093	19.010	16.126	5.033	57.302	32
	LL7	11.174	17.638	15.300	4.126	56.665	35
	LL8	12.597	19.287	16.890	4.293	55.835	39
Plastic Limit	PL1	12.873	15.813	15.072	2.199	33.697	PL=33.3
	PL2	17.815	26.987	24.719	6.904	32.851	

Liquid Limit Calculation

Method 1: Multiple Point Method

Plot moisture content Vs N graph and w at N=25 is LL

From MC Vs N plot, moisture content at N=25 is 58.5%

Therefore, Liquid Limit = **58.5**

Method 2: One Point Method

Taking data from test # LL4

N=22 at w=59.123%

so, LL=w*(N/25)^(0.121)= 58.215773

Plastic Limit Calculation

|PL1-PL2|<1% so test ok

Plastic limit=average of both= **33.3**

Plasticity Index (PI)=LL-PL= **25.2**

APPENDIX C

MINIATURE PROCTOR TEST

Table C-1-a Miniature Proctor Test Data of EPK clay

Volume of mold= 0.00217 ft^3 = 61.4476 cc

Specific Gravity =	2.590				
Test	1	2	3	4	5
Target Moisture Content (%)	28	32	34	36	40
Weight of Soil (gm)	100.00	100.00	100.00	100.00	100.00
Weight of Soil + Cement (gm)	100.0	100.0	100.0	100.0	100.0
Target Weight of Water (gm)	28.000	32.000	34.000	36.000	40.000
Weight of Mold (gm)	125.470	125.470	125.470	125.470	125.470
Weight of Mold +Moist Soil (gm)	227.280	233.540	236.910	235.460	231.670
Weight of Moist Soil (gm)	101.810	108.070	111.440	109.990	106.200
Moist Unit Weight (gm/cm^3)	1.657	1.759	1.814	1.790	1.728
Moist Unit Weight (lb/ft^3)	103.434	109.794	113.218	111.745	107.895

Table C-1-b Miniature Proctor Test Data of EPK clay

Moisture Can#	1	2	3	4	5	6	7	8	9	10
Weight of Moisture Can (gm)	10.920	10.650	11.190	11.330	11.120	11.090	10.900	11.070	11.200	11.070
Weight of Can + Moist Soil (gm)	21.060	25.520	23.480	19.590	29.310	25.080	25.750	25.820	26.960	24.630
Weight of Can + Dry Soil (lb)	18.730	22.160	20.440	17.550	24.590	21.440	21.740	21.870	22.410	20.690
Moisture Content (%)	29.834	29.192	32.865	32.797	35.041	35.169	36.993	36.574	40.589	40.956
	29.513		32.318		35.105		36.783		40.773	
Dry Unit Weight of Compaction (lb/ft^3)	79.864		82.657		83.800		81.695		76.645	
Zero Air Void (lb/ft^3)	91.599		87.345		84.650		82.766		78.607	

Table C-2-a Miniature Proctor Test Data of EPK clay + 5% Cement

Volume of mold= 0.00217 ft^3 = 61.4476 cc

Specific Gravity =	2.638				
Test	1	2	3	4	5
Target Moisture Content (%)	30	34	36	38	40
Weight of Soil (gm)	96.00	96.00	96.00	96.00	96.00
Weight of Cement (gm)	4.80	4.80	4.80	4.80	4.80
Weight of Soil + Cement (gm)	100.80	100.8	100.8	100.8	100.8
Target Weight of Water (gm)	30.240	34.272	36.288	38.304	40.320
Weight of Mold (gm)	125.460	125.470	125.470	125.470	125.470
Weight of Mold +Moist Soil (gm)	222.400	230.870	233.06	233.8	232.400
Weight of Moist Soil (gm)	96.940	105.400	107.590	108.330	106.930
Moist Unit Weight (gm/cm^3)	1.578	1.715	1.751	1.763	1.740
Moist Unit Weight (lb/ft^3)	98.487	107.082	109.307	110.058	108.636

Table C-2-b Miniature Proctor Test Data of EPK clay + 5% Cement

Target Moisture Content (%)	30		34		36		38		40	
Moisture Can#	1	2	3	4	5	6	7	8	9	10
Weight of Moisture Can (gm)	10.600	11.070	10.870	11.310	11.090	11.190	11.040	11.120	11.200	10.890
Weight of Can + Moist Soil (gm)	19.550	18.490	21.420	22.430	22.080	22.760	20.160	20.400	22.960	23.800
Weight of Can + Dry Soil (lb)	17.440	16.760	18.700	19.550	19.140	19.700	17.610	17.850	19.540	20.070
Moisture Content (%)	30.848	30.404	34.738	34.951	36.522	35.958	38.813	37.890	41.007	40.632
	30.626		34.845		36.240		38.357		40.820	
Dry Unit Weight of Compaction (lb/ft^3)	75.396		79.411		80.231		79.550		77.146	
Zero Air Void (lb/ft^3)	91.050		85.770		84.157		81.826		79.261	

Table C-3-a Miniature Proctor Test Data of EPK clay + 10% Cement

Volume of mold= 0.00217 ft^3 = 61.4476 cc

Specific Gravity =	2.647				
Test	1	2	3	4	5
Target Moisture Content (%)	30	34	36	38	40
Weight of Soil (gm)	91.00	91.00	91.00	91.00	91.00
Weight of Cement (gm)	9.10	9.10	9.10	9.10	9.10
Weight of Soil + Cement (gm)	100.1	100.1	100.1	100.1	100.1
Target Weight of Water (gm)	30.030	34.034	36.036	38.038	40.040
Weight of Mold (gm)	125.470	125.470	125.470	125.470	125.470
Weight of Mold +Moist Soil (gm)	221.980	231.370	234.800	235.530	231.520
Weight of Moist Soil (gm)	96.510	105.900	109.330	110.060	106.050
Moist Unit Weight (gm/cm^3)	1.571	1.723	1.779	1.791	1.726
Moist Unit Weight (lb/ft^3)	98.050	107.590	111.074	111.816	107.742

Table C-3-b Miniature Proctor Test Data of EPK clay + 10% Cement

Target Moisture Content (%)	30		34		36		38		40	
Moisture Can#	2	2'	3	3'	4	4'	5	5'	6	6'
Weight of Moisture Can (gm)	29.960	29.710	30.360	30.540	30.460	30.250	30.620	30.440	14.030	30.640
Weight of Can + Moist Soil (gm)	57.730	53.690	50.590	52.750	57.630	57.010	47.830	50.790	29.430	47.750
Weight of Can + Dry Soil (lb)	51.180	48.050	45.400	47.050	50.430	49.950	43.110	45.180	24.790	42.650
Moisture Content (%)	30.867	30.752	34.508	34.525	36.054	35.838	37.790	38.060	43.123	42.465
	30.810		34.516		35.946		37.925		42.794	
Dry Unit Weight of Compaction (lb/ft^3)	74.956		79.983		81.705		81.070		75.453	
Zero Air Void (lb/ft^3)	90.977		86.313		84.640		82.427		77.446	

Table C-4-a Miniature Proctor Test Data of EPK clay + 5% Cement + 0.5% Fiber

Volume of mold= 0.00217 ft^3 = 61.4476 cc

Specific Gravity =	2.624				
Test	1	2	3	4	5
Target Moisture Content (%)	30	34	36	38	40
Weight of Soil (gm)	95.00	95.00	95.00	95.00	95.00
Weight of Cement (gm)	4.75	4.75	4.75	4.75	4.75
Weight of Fiber (gm)	0.48	0.48	0.48	0.48	0.48
Total Weight of Soil + Cement + Fiber (gm)	100.2	100.2	100.2	100.2	100.2
Target Weight of Water (gm)	30.068	34.077	36.081	38.086	40.090
Weight of Mold (gm)	125.470	125.470	125.470	125.470	125.470
Weight of Mold + Moist Soil (gm)	219.230	229.870	232.977	233.730	231.86
Weight of Moist Soil (gm)	93.760	104.400	107.507	108.260	106.390
Moist Unit Weight (gm/cm^3)	1.526	1.699	1.750	1.762	1.731
Moist Unit Weight (lb/ft^3)	95.256	106.066	109.222	109.987	108.088

Table C-4-b Miniature Proctor Test Data of EPK clay + 5% Cement + 0.5% Fiber

Target Moisture Content (%)	30		34		36		38		40	
Moisture Can#	1	2	3	4	5	6	7	8	9	10
Weight of Moisture Can (gm)	29.960	29.700	30.360	30.540	30.430	30.250	30.600	30.430	30.300	30.630
Weight of Can + Moist Soil (gm)	50.440	47.030	45.610	49.450	46.600	52.330	49.840	50.160	51.910	48.790
Weight of Can + Dry Soil (lb)	45.780	43.110	41.670	44.590	42.250	46.430	44.590	44.780	45.450	43.430
Moisture Content (%)	29.456	29.232	34.836	34.591	36.802	36.465	37.527	37.491	42.640	41.875
	29.344		34.714		36.633		37.509		42.258	
Dry Unit Weight of Compaction (lb/ft^3)	73.645		78.734		79.938		79.986		75.980	
Zero Air Void (lb/ft^3)	92.508		85.687		83.486		82.519		77.643	

Table C-5-a Miniature Proctor Test Data of EPK clay + 10% Cement + 0.5% Fiber

Specific Gravity =	2.64				
Test	1	2	3	4	5
Target Moisture Content (%)	30	34	36	38	40
Weight of Soil (gm)	100.00	100.00	100.00	100.00	100.00
Weight of Cement (gm)	10.00	10.00	10.00	10.00	10.00
Weight of Fiber (gm)	0.50	0.50	0.50	0.50	0.50
Total Weight of Soil + Cement + Fiber (gm)	110.5	110.5	110.5	110.5	110.5
Target Weight of Water (gm)	33.150	37.570	39.780	41.990	44.200
Weight of Mold (gm)	125.470	125.470	125.470	125.470	125.470
Weight of Mold +Moist Soil (gm)	221.470	230.390	235.470	235.170	233.850
Weight of Moist Soil (gm)	96.000	104.920	110.000	109.700	108.380
Moist Unit Weight (gm/cm^3)	1.562	1.707	1.790	1.785	1.764
Moist Unit Weight (lb/ft^3)	97.532	106.594	111.755	111.450	110.109

Table C-5-b Miniature Proctor Test Data of EPK clay + 10% Cement + 0.5% Fiber

Target Moisture Content (%)	30		34		36		38		40	
Moisture Can#	1	2	3	4	5	6	7	8	9	10
Weight of Moisture Can (gm)	29.980	29.710	30.460	30.240	30.610	30.450	30.370	30.520	30.640	14.050
Weight of Can + Moist Soil (gm)	49.160	45.200	50.660	50.850	49.060	57.660	52.260	51.820	51.560	28.300
Weight of Can + Dry Soil (lb)	44.700	41.600	45.500	45.580	44.120	50.430	46.230	46.020	45.550	24.220
Moisture Content (%)	30.299	30.278	34.309	34.355	36.566	36.186	38.020	37.419	40.309	40.118
	30.288		34.332		36.376		37.720		40.213	
Dry Unit Weight of Compaction (lb/ft^3)	74.858		79.351		81.946		80.925		78.530	
Zero Air Void (lb/ft^3)	91.443		86.328		83.954		82.463		79.832	

Table C-6 Miniature Proctor Test Data: Summary

EPK Clay		Soil+ 5% Cement		Soil + 10% Cement		Soil + 5% Cement + 0.5% Fiber		Soil+ 10% Cement + 0.5% Fiber	
MC	Υ_d (lb/ft^3)	MC	Υ_d (lb/ft^3)	MC	Υ_d (lb/ft^3)	MC	Υ_d (lb/ft^3)	MC	Υ_d (lb/ft^3)
29.513	79.86	30.63	75.40	30.81	74.96	29.34	73.65	30.29	74.86
32.831	82.66	34.84	79.41	34.52	79.98	34.71	78.73	34.33	79.35
35.105	83.80	36.24	80.23	35.95	81.70	36.63	79.94	36.38	81.95
36.783	81.69	38.35	79.55	37.92	81.07	37.51	79.99	37.72	80.93
40.773	76.64	40.82	77.15	42.79	75.45	42.26	75.98	40.21	78.53

APPENDIX D

PLASTICITY TEST

Test D-1 Plasticity Test Data of EPK Clay

Calibration factor: 10 division = 1 mm

Liquid Limit Test

Can#	**Weight in gm**					Water (%)	Dial gage Reading	Penetration (mm)
	Can	Can + wet	Can + Dry	Water	Dry			
1	30.82	55.96	46.64	9.320	15.820	58.913	160	16
2	30.37	52.45	44.09	8.360	13.720	60.933	195	19.5
3	30.65	60.42	49.09	11.330	18.440	61.443	200	20
4	30.57	52.43	43.98	8.450	13.410	63.013	220	22
5	30.9	48.68	41.64	7.040	10.740	65.549	250	25

Plastic Limit Test

Can#	**Weight in gm**					Water (%)	Plastic Limit
	Can	Can + wet	Can + Dry	Water	Dry		
6	12.873	15.813	15.072	0.741	2.199	33.697	33.274
7	17.815	26.987	24.719	2.268	6.904	32.851	

From Moisture Content Vs. Penetration graph, moisture content at 20 mm penetration (LL) = 61.5%

Plastic Limit (PL) = 33.3%

Plastic Index (PI) = 28.2

Test D-2 Plasticity Test Data of EPK Clay + 5% Cement

Calibration factor: 10 division = 1 mm

Liquid Limit Test

Can#	Weight in gm					Water (%)	Dial gage Reading	Penetration (mm)
	Can	Can + wet	Can + Dry	Water	Dry			
1	30.36	46.13	39.39	6.740	9.030	74.640	175	17.5
2	29.96	42.15	36.89	5.260	6.930	75.902	190	19
3	30.45	45.06	38.54	6.520	8.090	80.593	240	24
4	30.53	55.25	44.18	11.070	13.650	81.099	255	25.5

Plastic Limit Test

Can#	Weight in gm					Water (%)	Plastic Limit
	Can	Can + wet	Can + Dry	Water	Dry		
5	30.610	36.620	34.900	1.720	4.290	40.093	40.534
6	30.630	36.410	34.730	1.680	4.100	40.976	

From moisture content Vs. penetration graph, moisture content at 20 mm penetration (LL) = 77.00%

Plastic Limit (PL) = 40.5%

Plastic Index (PI) = 36.5

Test D-3 Plasticity Test Data of EPK Clay + 10% Cement

Calibration factor: 10 division = 1 mm

Liquid Limit Test

Can#	Weight in gm					Water (%)	Dial gage Reading	Penetration (mm)
	Can	Can + wet	Can + Dry	Water	Dry			
1	29.97	47.98	41.04	6.940	11.070	62.692	115	11.5
2	30.62	50.4	42.09	8.310	11.470	72.450	170	17
3	30.3	66.57	50.88	15.690	20.580	76.239	200	20
4	30.45	65.54	49.7	15.840	19.250	82.286	245	24.5

Plastic Limit Test

Can#	Weight in gm					Water (%)	Plastic Limit (PL)
	Can	Can + wet	Can + Dry	Water	Dry		
5	11.180	15.670	14.370	1.300	3.190	40.752	40.654
6	11.190	16.250	14.790	1.460	3.600	40.556	

From moisture content Vs. penetration graph, moisture content at 20 mm penetration (LL) = 75.5%

Plastic Limit (PL) = 40.7%

Plastic Index (PI) = 34.8%

APPENDIX E

WETTING-DRYING TEST

Test E-1 Wetting-Drying Test Data of EPK Clay (WD_0C)

Molding Data (WD_0C)

Test Start Date: 10/6/2018

For each sample:

OMC=	35	%
MDD=	83.8	lb/ft^3
Soil=	1500	gm
Cement=	0	gm
Fiber=	0	gm
Total Soil + Cement + Fiber=	1500	gm
Water=	525	gm
Volume of mold (ft^3)=	0.0333	ft^3
Volume of mold (cc)=	943.895	cc
1 gm/cc=	62.428	lb/ft3

Sample	#1	#2	#3
Mass of mold (gm)=	2028.1	2028.1	2028.1
Mass of mold + compacted specimen (gm) =	3691.163	3709.18	3714.31
Mass of compacted specimen (gm)=	1663.063	1681.08	1686.21
Moist density of compacted specimen (gm/cc) =	1.762	1.781	1.786

Molding Data Continue (WD_0C)

Sample	#1		#2		#3	
Moisture Can No.	1	2	3	4	5	6
Mass of Moisture Can (gm)	29.72	30.39	30.32	30.25	30.46	30.32
Mass of Can + Moist Soil (gm)	83.02	105.1	97.45	105.6	91.27	103.86
Mass of Can + Dry Soil (gm)	68.91	85.46	79.68	85.89	75.48	85.12
Moisture Content (%)	36.00	35.72	36.00	35.42	35.07	34.20
Average Moisture Content (%)	35.861		35.712		34.635	
Dry Unit Mass of Compaction (gm/cc)	1.297		1.312		1.327	
Dry Unit Mass of Compaction (lb/ft^3)	80.96		81.93		82.83	
Difference in MC and OMC (%)	0.86		0.71		0.36	
Difference in dry density and MDD (lb/ft^3)	2.84		1.87		0.97	

Difference between OMC and moisture content of specimen < 1%, OK

Difference between MDD and dry density of specimen < 3 lb/ft^3, OK

Initial Procedure	Sample No.	Sample 1				Sample 2	Sample 3
	Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
After Molding Date: 10/06/2018	Mass (gm)=	1661.14			57.32	1680.25	1685.42
	Mass (lb)=	3.662				3.704	3.716
	Diameter (in)=	3.973	3.995	3.974			
	Height (in)=	4.618	4.6	4.601			
After 7 days storage period	Mass (gm)=	1643.61			56.97	1669.55	1679.37
	Mass (lb)=	3.624				3.681	3.702
	Diameter (in)=	3.975	3.98	3.98			
	Height (in)=	4.615	4.598	4.538			
Original Dry Mass (gm)		**1209.772**				**1230.211**	**1247.348**
Original Dry Mass (lb)		**2.667**				**2.712**	**2.750**

Wetting-Drying Cycle Data of EPK clay sample (WD_0C)

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 1	After 5 hrs. immersion	Mass (gm)=	1637.270			55.208	1643.630	1593.200
		Mass (lb)=	3.610				3.624	3.512
		Diameter (in)=	3.975	3.98	3.88			
		Height (in)=	4.505	4.515	4.53			
	After 42 hrs. oven dried at 71°C	Mass (gm)=	1228.750			48.709	1229.440	1192.390
		Mass (lb)=	2.709				2.710	2.629
		Diameter (in)=	3.794	3.787	3.795			
		Height (in)=	4.280	4.299	4.360			
	After giving firm strokes	Mass (gm)=					1220.590	1183.070
		Mass (lb)=					2.691	2.608
End of 1st Cycle								
Cycle 2	After 5 hrs. immersion	Mass (gm)=	All three samples collapsed completely					
		Mass (lb)=						
		Diameter (in)=						
		Height (in)=						
	After 42 hrs. oven dried at 71°C	Mass (gm)=						
		Mass (lb)=						
		Diameter (in)=						
		Height (in)=						
	After giving firm strokes	Mass (gm)=						
		Mass (lb)=						
End of 2nd Cycle								

Test E-2 Wetting-Drying Test Data of EPK Clay + 5% Cement (WD_5C)

Molding Data (WD_5C)

Test Start Date: 11/16/2018

For each sample:

OMC=	36.300	%
MDD=	80.300	lb/ft^3
Soil=	1350.000	gm
Cement=	67.500	gm
Fiber=	0.000	gm
Total Soil + Cement + Fiber=	1417.5	gm
Water=	514.5525	gm
Volume of mold (ft^3)=	0.0333	ft^3
Volume of mold (cc)=	943.895	cc
1 gm/cc=	62.428	lb/ft3

Sample	#1	#2	#3
Mass of mold (gm)=	2027.900	2027.900	2027.900
Mass of mold + compacted specimen (gm) =	3695.180	3681.280	3685.530
Mass of compacted specimen (gm)=	1667.280	1653.380	1657.630
Moist density of compacted specimen (gm/cc) =	1.766	1.752	1.756

Molding Data Continue (WD_5C)

Sample	#1		#2		#3	
Moisture Can No.	1	2	3	4	5	6
Mass of Moisture Can (gm)	29.960	29.710	30.380	30.540	30.460	30.250
Mass of Can + Moist Soil (gm)	104.720	104.620	91.540	128.740	121.470	128.700
Mass of Can + Dry Soil (gm)	84.430	84.430	74.980	101.990	96.730	101.980
Moisture Content (%)	37.250	36.897	37.130	37.439	37.332	37.251
Average Moisture Content (%)	37.073		37.284		37.291	
Dry Unit Mass of Compaction (gm/cc)	1.289		1.276		1.279	
Dry Unit Mass of Compaction (lb/ft^3)	80.447		79.654		79.855	
Difference in MC and OMC (%)	0.773		0.984		0.991	
Difference in dry density and MDD (lb/ft^3)	0.147		0.646		0.445	

Difference between OMC and moisture content of specimen < 1%, OK

Difference between MDD and dry density of specimen < 3 lb/ft^3, OK

Initial Procedure	Sample No.	Sample 1				Sample 2	Sample 3
	Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
After Molding Date: 10/06/2018	Mass (gm)=	1667.080			57.262	1652.520	1657.000
	Mass (lb)=	3.675				3.643	3.653
	Diameter (in)=	3.980	3.982	3.988			
	Height (in)=	4.589	4.606	4.590			
After 7 days storage period	Mass (gm)=	1659.480			56.963	1649.100	1654.270
	Mass (lb)=	3.659				3.636	3.647
	Diameter (in)=	3.991	3.981	3.985			
	Height (in)=	4.568	4.556	4.573			
Original Dry Mass (gm)		**1210.651**				**1201.229**	**1204.933**
Original Dry Mass (lb)		**2.669**				**2.648**	**2.656**

Wetting-Drying Cycle Data of EPK clay + 5% Cement (WD_5C)

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 1	After 5 hrs immersion	Mass (gm)=	1663.140			56.779	1652.380	1658.310
		Mass (lb)=	3.667				3.643	3.656
		Diameter (in)=	3.981	3.983	3.978			
		Height (in)=	4.586	4.551	4.550			
	After 42 hrs oven dried at 71^{o}C	Mass (gm)=	1294.030			52.187	1273.140	1278.560
		Mass (lb)=	2.853				2.807	2.819
		Diameter (in)=	3.886	3.864	3.863			
		Height (in)=	4.434	4.460	4.409			
	After giving firm strokes	Mass (gm)=					1270.620	1276.040
		Mass (lb)=					2.801	2.813
End of 1st Cycle								
Cycle 2	After 5 hrs immersion	Mass (gm)=	1549.230			52.519	1539.010	1511.920
		Mass (lb)=	3.415				3.393	3.333
		Diameter (in)=	3.891	3.896	3.851			
		Height (in)=	4.436	4.428	4.466			
	After 42 hrs oven dried at 71^{o}C	Mass (gm)=	1202.270				1221.270	1206.320
		Mass (lb)=	2.651				2.692	2.659
		Diameter (in)=	Non-Uniform due to deterioration					
		Height (in)=						
	After giving firm strokes	Mass (gm)=					1160.290	1142.710
		Mass (lb)=					2.558	2.519
End of 2nd Cycle								

Cycles	Procedure	Sample No.	Sample 1		Sample 2	Sample 3
		Parameter	Mass/diameter/height	Avg. Vol. in^3	Mass	Mass
Cycle 3	After 5 hrs immersion	Mass (gm)=	1444.560		1441.750	1407.840
		Mass (lb)=	3.185		3.179	3.104
		Diameter (in)=	Non-Uniform due to deterioration			
		Height (in)=				
	After 42 hrs oven dried at 71^{o}C	Mass (gm)=	1156.850		1141.550	1119.930
		Mass (lb)=	2.550		2.517	2.469
		Diameter (in)=	Non-Uniform due to deterioration			
		Height (in)=				
	After giving firm strokes	Mass (gm)=			1111.690	1066.160
		Mass (lb)=			2.451	2.350
End of 3rd Cycle						
Cycle 4	After 5 hrs immersion	Mass (gm)=	1407.890		1399.880	1329.630
		Mass (lb)=	3.104		3.086	2.931
		Diameter (in)=	Non-Uniform due to deterioration			
		Height (in)=				
	After 42 hrs oven dried at 71^{o}C	Mass (gm)=	1115.160		Collapsed	1056.150
		Mass (lb)=	2.459			2.328
		Diameter (in)=	Non-Uniform due to deterioration			
		Height (in)=				
	After giving firm strokes	Mass (gm)=				954.320
		Mass (lb)=				2.104
Final	Oven dried at 110^{o}C	Mass (gm)=	1051.800			914.540
		Mass (lb)=	2.319			2.016
		Diameter (in)=	Non-Uniform due to deterioration			
		Height (in)=				

Test E-3 Wetting-Drying Test Data of EPK Clay + 10% Cement (WD_10C)

Molding Data (WD_10C)

Test Start Date: 2/22/2019

For each sample:

OMC=	36.000	%
MDD=	81.800	lb/ft^3
Soil=	1300.000	gm
Cement=	130.000	gm
Fiber=	0.000	gm
Total Soil + Cement + Fiber=	1430.000	gm
Water=	514.800	gm
Volume of mold (ft^3)=	0.033	ft^3
Volume of mold (cc)=	943.895	cc
1 gm/cc=	62.428	lb/ft3

Sample	#1	#2	#3
Mass of mold (gm)=	2027.500	2027.500	2027.500
Mass of mold + compacted specimen (gm) =	3717.370	3714.930	3706.540
Mass of compacted specimen (gm)=	1689.870	1687.430	1679.040
Moist density of compacted specimen (gm/cc) =	1.790	1.788	1.779

Molding Data Continue (WD_10C)

Sample	#1		#2		#3	
Moisture Can No.	1	2	3	4	5	6
Mass of Moisture Can (gm)	30.250	30.620	30.540	30.460	29.960	29.710
Mass of Can + Moist Soil (gm)	102.960	95.160	111.180	148.700	116.510	114.160
Mass of Can + Dry Soil (gm)	84.030	78.489	90.107	118.160	94.024	92.282
Moisture Content (%)	35.199	34.826	35.377	34.823	35.099	34.965
Average Moisture Content (%)	35.013		35.100		35.032	
Dry Unit Mass of Compaction (gm/cc)	1.326		1.323		1.317	
Dry Unit Mass of Compaction (lb/ft^3)	82.782		82.609		82.239	
Difference in MC and OMC (%)	0.987		0.900		0.968	
Difference in dry density and MDD (lb/ft^3)	0.982		0.809		0.439	

Difference between OMC and moisture content of specimen < 1%, OK

Difference between MDD and dry density of specimen < 3 lb/ft^3, OK

Initial Procedure	Sample No.	Sample 1				Sample 2	Sample 3
	Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
After Molding Date: 10/06/2018	Mass (gm)=	1677.700			57.259	1686.060	1688.320
	Mass (lb)=	3.699				3.717	3.722
	Diameter (in)=	3.995	3.990	3.989			
	Height (in)=	4.606	4.565	4.558			
After 7 days storage period	Mass (gm)=	1675.720			57.153	1685.510	1687.400
	Mass (lb)=	3.694				3.716	3.720
	Diameter (in)=	3.995	3.992	3.965			
	Height (in)=	4.602	4.562	4.590			
Original Dry Mass (gm)		**1241.158**				**1247.601**	**1249.631**
Original Dry Mass (lb)		**2.736**				**2.750**	**2.755**

Wetting-Drying Cycle Data of EPK clay + 10% Cement (WD_10C)

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 1	After 5 hrs immersion	Mass (gm)=	1679.880			57.448	1686.930	1689.400
		Mass (lb)=	3.703				3.719	3.724
		Diameter (in)=	3.996	3.996	3.993			
		Height (in)=	4.585	4.6	4.564			
	After 42 hrs oven dried at 71°C	Mass (gm)=	1300.000			53.484	1321.370	1316.630
		Mass (lb)=	2.866				2.913	2.903
		Diameter (in)=	3.905	3.903	3.901			
		Height (in)=	4.474	4.481	4.456			
	After giving firm strokes	Mass (gm)=					1318.850	1314.660
		Mass (lb)=					2.908	2.898
End of 1st Cycle								
Cycle 2	After 5 hrs immersion	Mass (gm)=	1623.230			54.233	1630.900	1632.720
		Mass (lb)=	3.579				3.596	3.600
		Diameter (in)=	3.919	3.914	3.914			
		Height (in)=	4.478	4.528	4.505			
	After 42 hrs oven dried at 71°C	Mass (gm)=	1299.320			53.463	1312.720	1303.410
		Mass (lb)=	2.865				2.894	2.874
		Diameter (in)=	3.901	3.900	3.900			
		Height (in)=	4.461	4.492	4.471			
	After giving firm strokes	Mass (gm)=					1307.690	1300.050
		Mass (lb)=					2.883	2.866
End of 2nd Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 3	After 5 hrs immersion	Mass (gm)=	1622.360			54.587	1626.670	1617.100
		Mass (lb)=	3.577				3.586	3.565
		Diameter (in)=	3.99	3.904	3.91			
		Height (in)=	4.511	4.497	4.46			
	After 42 hrs oven dried at 71^{o}C	Mass (gm)=	1292.860			53.527	1310.350	1297.120
		Mass (lb)=	2.850				2.889	2.860
		Diameter (in)=	3.901	3.900	3.900			
		Height (in)=	4.478	4.490	4.472			
	After giving firm strokes	Mass (gm)=					1297.030	1289.970
		Mass (lb)=					2.859	2.844
End of 3rd Cycle								
Cycle 4	After 5 hrs immersion	Mass (gm)=	1621.800			53.444	1608.630	1608.010
		Mass (lb)=	3.575				3.546	3.545
		Diameter (in)=	3.917	3.903	3.878			
		Height (in)=	4.495	4.469	4.462			
	After 42 hrs oven dried at 71^{o}C	Mass (gm)=	1296.860			53.650	1289.570	1286.600
		Mass (lb)=	2.859				2.843	2.836
		Diameter (in)=	3.900	3.898	3.906			
		Height (in)=	4.441	4.541	4.482			
	After giving firm strokes	Mass (gm)=					1286.210	1281.610
		Mass (lb)=					2.836	2.825
End of 4th Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 5	After 5 hrs immersion	Mass (gm)=	1620.940			53.816	1598.620	1600.710
		Mass (lb)=	3.574				3.524	3.529
		Diameter (in)=	3.915	3.903	3.908			
		Height (in)=	4.488	4.479	4.488			
	After 42 hrs oven dried at 71^{o}C	Mass (gm)=	1297.200			53.499	1287.940	1284.440
		Mass (lb)=	2.860				2.839	2.832
		Diameter (in)=	3.899	3.896	3.920			
		Height (in)=	4.487	4.446	4.468			
	After giving firm strokes	Mass (gm)=					1280.960	1271.980
		Mass (lb)=					2.824	2.804
End of 5th Cycle								
Cycle 6	After 5 hrs immersion	Mass (gm)=	1621.920			53.840	1591.490	1586.060
		Mass (lb)=	3.576				3.509	3.497
		Diameter (in)=	3.913	3.903	3.914			
		Height (in)=	4.455	4.494	4.503			
	After 42 hrs oven dried at 71^{o}C	Mass (gm)=	1291.900			53.355	1276.650	1266.900
		Mass (lb)=	2.848				2.815	2.793
		Diameter (in)=	3.904	3.897	3.903			
		Height (in)=	4.492	4.464	4.434			
	After giving firm strokes	Mass (gm)=					1266.110	1261.050
		Mass (lb)=					2.791	2.780
End of 6th Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 7	After 5 hrs immersion	Mass (gm)=	1261.240			53.838	1576.610	1577.670
		Mass (lb)=	2.781				3.476	3.478
		Diameter (in)=	3.911	3.906	3.921			
		Height (in)=	4.471	4.464	4.498			
	After 42 hrs oven dried at 71^{o}C	Mass (gm)=	1285.390			53.546	1258.610	1254.490
		Mass (lb)=	2.834				2.775	2.766
		Diameter (in)=	3.905	3.900	3.899			
		Height (in)=	4.466	4.492	4.480			
	After giving firm strokes	Mass (gm)=					1250.650	1245.830
		Mass (lb)=					2.757	2.747
End of 7th Cycle								
Cycle 8	After 5 hrs immersion	Mass (gm)=	1622.350			53.881	1566.840	1566.740
		Mass (lb)=	3.577				3.454	3.454
		Diameter (in)=	3.913	3.903	3.914			
		Height (in)=	4.494	4.5	4.468			
	After 42 hrs oven dried at 71^{o}C	Mass (gm)=	1288.520			53.584	1250.070	1246.780
		Mass (lb)=	2.841				2.756	2.749
		Diameter (in)=	3.906	3.904	3.906			
		Height (in)=	4.495	4.471	4.454			
	After giving firm strokes	Mass (gm)=					1243.210	1239.270
		Mass (lb)=					2.741	2.732
End of 8th Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 9	After 5 hrs immersion	Mass (gm)=	1621.840			54.038	1557.670	1556.200
		Mass (lb)=	3.576				3.434	3.431
		Diameter (in)=	3.911	3.922	3.912			
		Height (in)=	4.503	4.476	4.488			
	After 42 hrs oven dried at 71°C	Mass (gm)=	1289.960			53.704	1243.410	1239.510
		Mass (lb)=	2.844				2.741	2.733
		Diameter (in)=	3.907	3.907	3.909			
		Height (in)=	4.493	4.478	4.463			
	After giving firm strokes	Mass (gm)=					1239.550	1234.570
		Mass (lb)=					2.733	2.722
End of 9th Cycle								
Cycle 10	After 5 hrs immersion	Mass (gm)=	1621.180			53.839	1552.490	1551.620
		Mass (lb)=	3.574				3.423	3.421
		Diameter (in)=	3.913	3.911	3.915			
		Height (in)=	4.487	4.46	4.484			
	After 42 hrs oven dried at 71°C	Mass (gm)=	1292.590			53.508	1237.950	1233.800
		Mass (lb)=	2.850				2.729	2.720
		Diameter (in)=	3.906	3.906	3.907			
		Height (in)=	4.487	4.465	4.442			
	After giving firm strokes	Mass (gm)=					1227.130	957.180
		Mass (lb)=					2.705	2.110
End of 10th Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 11	After 5 hrs immersion	Mass (gm)=	1621.730			53.683	1538.060	Collapsed
		Mass (lb)=	3.575				3.391	
		Diameter (in)=	3.911	3.905	3.923			
		Height (in)=	4.484	4.457	4.451			
	After 42 hrs oven dried at 71°C	Mass (gm)=	1290.400			53.683	1225.290	
		Mass (lb)=	2.845				2.701	
		Diameter (in)=	3.903	3.899	3.920			
		Height (in)=	4.453	4.475	4.503			
	After giving firm strokes	Mass (gm)=					1206.910	
		Mass (lb)=					2.661	
End of 11th Cycle								
Cycle 12	After 5 hrs immersion	Mass (gm)=	1622.050			54.098	1514.550	
		Mass (lb)=	3.576				3.339	
		Diameter (in)=	3.911	3.908	3.922			
		Height (in)=	4.507	4.503	4.481			
	After 42 hrs oven dried at 71°C	Mass (gm)=	1288.650			53.837	1206.580	
		Mass (lb)=	2.841				2.660	
		Diameter (in)=	3.902	3.901	3.917			
		Height (in)=	4.493	4.531	4.450			
	After giving firm strokes	Mass (gm)=					1201.130	
		Mass (lb)=					2.648	
End of 12th Cycle								
Final	Oven dried at 110°C	Mass (gm)=	1263.690			53.572	1179.140	
		Mass (lb)=	2.786				2.600	
		Diameter (in)=	3.912	3.894	3.903			
		Height (in)=	4.464	4.491	4.478			

Percent Loss of Soil Calculation for WD_10C

Mass/Sample	Sample 1	Sample 2	Sample 3
Original Calculated Dry Mass (gm)	1241.158	1247.601	1249.631
Final Oven Dried Mass (gm)	1263.690	1179.140	Collapsed
Mass of water of Hydration (%)	3.500		
Corrected Oven Dry Mass (gm)	1220.957	1139.266	
Soil-Cement loss (%)	1.628	8.683	

Compressive Strength Calculation for WD_10C

Samples	Load (lb)	Area (in^2)	Min. CS (psi)	Test time
Sample 1	5974	11.946	500.088	After 12 cycle
Sample 2	3772	11.684	322.836	After 12 cycle
Sample 3	Collapsed in 10th cycle			

Test E-4 Wetting-Drying Test Data of EPK Clay + 5% Cement + 0.5% Fiber (WD_5C_0.5F)

Molding Data (WD_5C_0.5F)

Test Start Date: 10/29/2018

For each sample:

OMC=	37.000	%
MDD=	80.100	lb/ft^3
Soil=	1400.000	gm
Cement=	70.000	gm
Fiber=	7.000	gm
Total Soil + Cement + Fiber=	1477.000	gm
Water=	546.490	gm
Volume of mold (ft^3)=	0.033	ft^3
Volume of mold (cc)=	943.895	cc
1 gm/cc=	62.428	lb/ft3

Sample	#1	#2	#3
Mass of mold (gm)=	2027.900	2027.900	2027.900
Mass of mold + compacted specimen (gm) =	3674.700	3665.140	3667.350
Mass of compacted specimen (gm)=	1646.800	1637.240	1639.450
Moist density of compacted specimen (gm/cc) =	1.745	1.735	1.737

Molding Data Continue (WD_5C_0.5F)

Sample	#1		#2		#3	
Moisture Can No.	1	2	3	4	5	6
Mass of Moisture Can (gm)	21.240	21.560	20.570	32.350	30.610	21.040
Mass of Can + Moist Soil (gm)	117.620	117.650	113.390	97.540	124.650	114.600
Mass of Can + Dry Soil (gm)	92.100	92.160	88.670	80.260	99.700	89.290
Moisture Content (%)	36.015	36.105	36.300	36.068	36.112	37.084
Average Moisture Content (%)	36.060		36.184		36.598	
Dry Unit Mass of Compaction (gm/cc)	1.282		1.274		1.272	
Dry Unit Mass of Compaction (lb/ft^3)	80.051		79.514		79.380	
Difference in MC and OMC (%)	0.940		0.816		0.402	
Difference in dry density and MDD (lb/ft^3)	0.049		0.586		0.720	

Difference between OMC and moisture content of specimen < 1%, OK

Difference between MDD and dry density of specimen < 3 lb/ft^3, OK

Initial Procedure	Sample No.	Sample 1				Sample 2	Sample 3
	Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
After Molding Date: 10/06/2018	Mass (gm)=	1634.010			56.990	1636.520	1637.520
	Mass (lb)=	3.602				3.608	3.610
	Diameter (in)=	3.991	3.987	3.984			
	Height (in)=	4.567	4.557	4.568			
After 7 days storage period	Mass (gm)=	1631.600			56.573	1626.540	1633.560
	Mass (lb)=	3.597				3.586	3.601
	Diameter (in)=	3.974	3.982	3.977			
	Height (in)=	4.553	4.552	4.553			
Original Dry Mass (gm)		**1199.179**				**1194.373**	**1195.886**
Original Dry Mass (lb)		**2.644**				**2.633**	**2.636**

Wetting-Drying Cycle Data of EPK clay + 5% Cement Sample + 0.5% Fiber (WD_5C_0.5F)

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 1	After 5 hrs immersion	Mass (gm)=	1640.520			56.919	1643.500	1640.360
		Mass (lb)=	3.617				3.623	3.616
		Diameter (in)=	3.998	3.991	3.994			
		Height (in)=	4.535	4.543	4.549			
	After 42 hrs oven dried at 71^{o}C	Mass (gm)=	1265.500			52.660	1256.550	1258.910
		Mass (lb)=	2.790				2.770	2.775
		Diameter (in)=	3.882	3.892	3.884			
		Height (in)=	4.430	4.450	4.440			
	After giving firm strokes	Mass (gm)=					1250.920	1254.510
		Mass (lb)=					2.758	2.766
End of 1st Cycle								
Cycle 2	After 5 hrs immersion	Mass (gm)=	1589.160			53.720	1587.360	1582.490
		Mass (lb)=	3.503				3.500	3.489
		Diameter (in)=	3.908	3.913	3.909			
		Height (in)=	4.474	4.473	4.475			
	After 42 hrs oven dried at 71^{o}C	Mass (gm)=	1255.660			52.879	1241.650	1249.760
		Mass (lb)=	2.768				2.737	2.755
		Diameter (in)=	3.891	3.895	3.891			
		Height (in)=	4.437	4.443	4.452			
	After giving firm strokes	Mass (gm)=					1213.070	1227.460
		Mass (lb)=					2.674	2.706
End of 2nd Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 3	After 5 hrs immersion	Mass (gm)=	1579.930			53.534	1543.660	1549.370
		Mass (lb)=	3.483				3.403	3.416
		Diameter (in)=	3.906	3.901	3.907			
		Height (in)=	4.465	4.493	4.454			
	After 42 hrs oven dried at 71^{o}C	Mass (gm)=	1244.100			52.729	1204.060	1217.840
		Mass (lb)=	2.743				2.654	2.685
		Diameter (in)=	3.891	3.891	3.888			
		Height (in)=	4.430	4.419	4.461			
	After giving firm strokes	Mass (gm)=					1185.059	1201.560
		Mass (lb)=					2.613	2.649
End of 3rd Cycle								
Cycle 4	After 5 hrs immersion	Mass (gm)=	1570.350			53.671	1511.690	1528.320
		Mass (lb)=	3.462				3.333	3.369
		Diameter (in)=	3.910	3.904	3.901			
		Height (in)=	4.478	4.484	4.482			
	After 42 hrs oven dried at 71^{o}C	Mass (gm)=	1239.700			52.694	1182.770	1202.440
		Mass (lb)=	2.733				2.608	2.651
		Diameter (in)=	3.891	3.887	3.886			
		Height (in)=	4.434	4.453	4.428			
	After giving firm strokes	Mass (gm)=					1160.400	1191.700
		Mass (lb)=					2.558	2.627
End of 4th Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 5	After 5 hrs immersion	Mass (gm)=	1565.000			53.015	1481.110	1512.950
		Mass (lb)=	3.450				3.265	3.335
		Diameter (in)=	3.890	3.903	3.885			
		Height (in)=	4.456	4.452	4.456			
	After 42 hrs oven dried at 71^{o}C	Mass (gm)=	1239.210			52.790	1162.270	1194.470
		Mass (lb)=	2.732				2.562	2.633
		Diameter (in)=	3.894	3.873	3.887			
		Height (in)=	4.457	4.459	4.446			
	After giving firm strokes	Mass (gm)=					1137.480	1183.530
		Mass (lb)=					2.508	2.609
End of 5th Cycle								
Cycle 6	After 5 hrs immersion	Mass (gm)=	1557.740			53.404	1445.520	1496.420
		Mass (lb)=	3.434				3.187	3.299
		Diameter (in)=	3.907	3.901	3.890			
		Height (in)=	4.462	4.506	4.448			
	After 42 hrs oven dried at 71^{o}C	Mass (gm)=	1237.490			52.390	1137.100	1186.920
		Mass (lb)=	2.728				2.507	2.617
		Diameter (in)=	3.869	3.883	3.880			
		Height (in)=	4.434	4.459	4.418			
	After giving firm strokes	Mass (gm)=					1129.000	1172.950
		Mass (lb)=					2.489	2.586
End of 6th Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 7	After 5 hrs immersion	Mass (gm)=	1550.620			52.866	1432.010	1476.280
		Mass (lb)=	3.419				3.157	3.255
		Diameter (in)=	3.894	3.865	3.896			
		Height (in)=	4.447	4.468	4.464			
	After 42 hrs oven dried at 71°C	Mass (gm)=	1228.790			52.320	1126.520	1159.850
		Mass (lb)=	2.709				2.484	2.557
		Diameter (in)=	3.860	3.860	3.889			
		Height (in)=	4.442	4.459	4.445			
	After giving firm strokes	Mass (gm)=					1103.000	1144.290
		Mass (lb)=					2.432	2.523
End of 7th Cycle								
Cycle 8	After 5 hrs immersion	Mass (gm)=	1544.740			53.024	1399.030	1453.250
		Mass (lb)=	3.406				3.084	3.204
		Diameter (in)=	3.897	3.848	3.920			
		Height (in)=	4.459	4.459	4.478			
	After 42 hrs oven dried at 71°C	Mass (gm)=	1212.590			52.295	1095.010	1148.940
		Mass (lb)=	2.673				2.414	2.533
		Diameter (in)=	3.880	3.852	3.866			
		Height (in)=	4.444	4.476	4.445			
	After giving firm strokes	Mass (gm)=					1080.160	1134.510
		Mass (lb)=					2.381	2.501
End of 8th Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 9	After 5 hrs immersion	Mass (gm)=	1539.210			53.085	1377.200	1433.380
		Mass (lb)=	3.393				3.036	3.160
		Diameter (in)=	3.900	3.872	3.885			
		Height (in)=	4.445	4.482	4.503			
	After 42 hrs oven dried at 71°C	Mass (gm)=	1214.230			52.303	1077.660	1122.610
		Mass (lb)=	2.677				2.376	2.475
		Diameter (in)=	3.890	3.858	3.877			
		Height (in)=	4.434	4.451	4.420			
	After giving firm strokes	Mass (gm)=					1065.340	1110.160
		Mass (lb)=					2.349	2.447
End of 9th Cycle								
Cycle 10	After 5 hrs immersion	Mass (gm)=	1533.380			52.800	1359.200	1415.330
		Mass (lb)=	3.381				2.997	3.120
		Diameter (in)=	3.908	3.867	3.878			
		Height (in)=	4.453	4.494	4.420			
	After 42 hrs oven dried at 71°C	Mass (gm)=	1205.830			52.435	1061.050	1111.680
		Mass (lb)=	2.658				2.339	2.451
		Diameter (in)=	3.892	3.855	3.887			
		Height (in)=	4.448	4.417	4.453			
	After giving firm strokes	Mass (gm)=					1045.610	1098.320
		Mass (lb)=					2.305	2.421
End of 10th Cycle								

<table>
<tr><td rowspan="2">Cycles</td><td rowspan="2">Procedure</td><td>Sample No.</td><td colspan="4">Sample 1</td><td>Sample 2</td><td>Sample 3</td></tr>
<tr><td>Parameter</td><td colspan="3">Mass/diameter/height</td><td>Avg. Vol. in^3</td><td>Mass</td><td>Mass</td></tr>
<tr><td rowspan="10">Cycle 11</td><td rowspan="4">After 5 hrs immersion</td><td>Mass (gm)=</td><td colspan="3">1525.910</td><td rowspan="4">52.829</td><td>1335.770</td><td>1395.900</td></tr>
<tr><td>Mass (lb)=</td><td colspan="3">3.364</td><td>2.945</td><td>3.077</td></tr>
<tr><td>Diameter (in)=</td><td>3.856</td><td>3.899</td><td>3.892</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Height (in)=</td><td>4.478</td><td>4.471</td><td>4.439</td></tr>
<tr><td rowspan="4">After 42 hrs oven dried at 71^{o}C</td><td>Mass (gm)=</td><td colspan="3">1201.120</td><td rowspan="4">52.276</td><td>1041.220</td><td>1095.270</td></tr>
<tr><td>Mass (lb)=</td><td colspan="3">2.648</td><td>2.295</td><td>2.415</td></tr>
<tr><td>Diameter (in)=</td><td>3.874</td><td>3.854</td><td>3.884</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Height (in)=</td><td>4.443</td><td>4.461</td><td>4.424</td></tr>
<tr><td rowspan="2">After giving firm strokes</td><td>Mass (gm)=</td><td colspan="4" rowspan="2"></td><td>1025.850</td><td>1082.930</td></tr>
<tr><td>Mass (lb)=</td><td>2.262</td><td>2.387</td></tr>
<tr><td colspan="9">End of 11th Cycle</td></tr>
<tr><td rowspan="10">Cycle 12</td><td rowspan="4">After 5 hrs immersion</td><td>Mass (gm)=</td><td colspan="3">1520.270</td><td rowspan="4">52.476</td><td>1313.810</td><td>1378.230</td></tr>
<tr><td>Mass (lb)=</td><td colspan="3">3.352</td><td>2.896</td><td>3.038</td></tr>
<tr><td>Diameter (in)=</td><td>3.863</td><td>3.893</td><td>3.859</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Height (in)=</td><td>4.455</td><td>4.474</td><td>4.443</td></tr>
<tr><td rowspan="4">After 42 hrs oven dried at 71^{o}C</td><td>Mass (gm)=</td><td colspan="3">1196.090</td><td rowspan="4">52.377</td><td>1023.070</td><td>1081.440</td></tr>
<tr><td>Mass (lb)=</td><td colspan="3">2.637</td><td>2.255</td><td>2.384</td></tr>
<tr><td>Diameter (in)=</td><td>3.883</td><td>3.843</td><td>3.888</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Height (in)=</td><td>4.413</td><td>4.478</td><td>4.458</td></tr>
<tr><td rowspan="2">After giving firm strokes</td><td>Mass (gm)=</td><td colspan="4" rowspan="2"></td><td>1005.040</td><td>1070.020</td></tr>
<tr><td>Mass (lb)=</td><td>2.216</td><td>2.359</td></tr>
<tr><td colspan="9">End of 12th Cycle</td></tr>
<tr><td rowspan="4">Final</td><td rowspan="4">Oven dried at 110^{o}C</td><td>Mass (gm)=</td><td colspan="3">1156.290</td><td rowspan="4">51.682</td><td>977.920</td><td>1037.190</td></tr>
<tr><td>Mass (lb)=</td><td colspan="3">2.549</td><td>2.156</td><td>2.287</td></tr>
<tr><td>Diameter (in)=</td><td>3.899</td><td>3.813</td><td>3.846</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Height (in)=</td><td>4.438</td><td>4.419</td><td>4.443</td></tr>
</table>

Percent Loss of Soil Calculation for WD_5C_0.5F

Mass/Sample	Sample 1	Sample 2	Sample 3
Original Calculated Dry Mass (gm)	1199.179	1194.373	1195.886
Final Oven Dried Mass (gm)	1156.290	977.920	1037.190
Mass of water of Hydration (%)	3.500		
Corrected Oven Dry Mass (gm)	1117.188	944.850	1002.116
Soil-Cement loss (%)	6.837	20.892	16.203

Compressive Strength Calculation for WD_5C_0.5F

Samples	Load (lb)	Area (in^2)	Min. CS (psi)	Test time
Sample 1	8595	11.660	737.154	After 12 cycle
Sample 2	3500	10.066	347.706	After 12 cycle
Sample 3	6085	10.839	561.375	After 12 cycle

Test E-5 Wetting-Drying Test Data of EPK Clay + 10% Cement + 0.5% Fiber (WD_10C_0.5F)

Molding Data (WD_10C_0.5F)

Test Start Date: 10/31/2018

For each sample:

OMC=	36.700	%
MDD=	82.000	lb/ft^3
Soil=	1300.000	gm
Cement=	130.000	gm
Fiber=	6.500	gm
Total Soil + Cement + Fiber=	1436.500	gm
Water=	527.196	gm
Volume of mold (ft^3)=	0.033	ft^3
Volume of mold (cc)=	943.895	cc
1 gm/cc=	62.428	lb/ft3

Sample	#1	#2	#3
Mass of mold (gm)=	2033.200	2033.200	2033.200
Mass of mold+compacted specimen (gm) =	3687.260	3681.670	3673.800
Mass of compacted specimen (gm)=	1654.060	1648.470	1640.600
Moist density of compacted specimen (gm/cc) =	1.752	1.746	1.738

Molding Data Continue (WD_10C_0.5F)

Sample	#1		#2		#3	
Moisture Can No.	1	2	3	4	5	6
Mass of Moisture Can (gm)	20.570	21.250	20.660	32.350	21.050	30.600
Mass of Can + Moist Soil (gm)	67.880	84.540	76.930	113.870	107.030	104.550
Mass of Can + Dry Soil (gm)	55.530	67.700	62.210	92.140	84.380	85.110
Moisture Content (%)	35.326	36.254	35.427	36.344	35.765	35.663
Average Moisture Content (%)	35.790		35.886		35.714	
Dry Unit Mass of Compaction (gm/cc)	1.291		1.285		1.281	
Dry Unit Mass of Compaction (lb/ft^3)	80.564		80.235		79.953	
Difference in MC and OMC (%)	0.910		0.814		0.986	
Difference in dry density and MDD (lb/ft^3)	1.436		1.765		2.047	

Difference between OMC and moisture content of specimen < 1%, OK

Difference between MDD and dry density of specimen < 3 lb/ft^3, OK

Initial Procedure	Sample No.	Sample 1				Sample 2	Sample 3
	Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
After Molding Date: 10/06/2018	Mass (gm)=	1652.150			56.906	1645.030	1639.700
	Mass (lb)=	3.642				3.627	3.615
	Diameter (in)=	3.991	3.992	3.985			
	Height (in)=	4.602	4.596	4.460			
After 7 days storage period	Mass (gm)=	1651.200			56.947	1644.030	1638.760
	Mass (lb)=	3.640				3.624	3.613
	Diameter (in)=	3.991	3.993	3.987			
	Height (in)=	4.605	4.594	4.462			
Original Dry Mass (gm)		**1215.995**				**1209.864**	**1207.509**
Original Dry Mass (lb)		**2.681**				**2.667**	**2.662**

Wetting-Drying Cycle Data of EPK clay + 10% Cement Sample + 0.5% Fiber (WD_10C_0.5F)

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 1	After 5 hrs immersion	Mass (gm)=	1654.840			57.453	1648.220	1644.470
		Mass (lb)=	3.648				3.634	3.625
		Diameter (in)=	3.998	3.993	3.995			
		Height (in)=	4.596	4.575	4.577			
	After 42 hrs oven dried at 71^oC	Mass (gm)=	1311.060			53.592	1299.880	1295.380
		Mass (lb)=	2.890				2.866	2.856
		Diameter (in)=	3.907	3.906	3.899			
		Height (in)=	4.476	4.476	4.479			
	After giving firm strokes	Mass (gm)=					1296.550	1292.010
		Mass (lb)=					2.858	2.848
End of 1st Cycle								
Cycle 2	After 5 hrs immersion	Mass (gm)=	1599.840			53.930	1587.150	1593.120
		Mass (lb)=	3.527				3.499	3.512
		Diameter (in)=	3.917	3.916	3.912			
		Height (in)=	4.499	4.45	4.491			
	After 42 hrs oven dried at 71^oC	Mass (gm)=	1302.570			53.683	1286.910	1289.320
		Mass (lb)=	2.872				2.837	2.842
		Diameter (in)=	3.907	3.900	3.908			
		Height (in)=	4.483	4.488	4.476			
	After giving firm strokes	Mass (gm)=					1281.250	1284.330
		Mass (lb)=					2.825	2.831
End of 2nd Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 3	After 5 hrs immersion	Mass (gm)=	1599.120			54.013	1574.070	1584.600
		Mass (lb)=	3.525				3.470	3.493
		Diameter (in)=	3.915	3.916	3.906			
		Height (in)=	4.495	4.489	4.495			
	After 42 hrs oven dried at 71°C	Mass (gm)=	1304.520			53.678	1281.710	1281.150
		Mass (lb)=	2.876				2.826	2.824
		Diameter (in)=	3.907	3.909	3.902			
		Height (in)=	4.482	4.485	4.472			
	After giving firm strokes	Mass (gm)=					1277.950	1276.230
		Mass (lb)=					2.817	2.814
End of 3rd Cycle								
Cycle 4	After 5 hrs immersion	Mass (gm)=	1601.950			54.127	1573.790	1579.080
		Mass (lb)=	3.532				3.470	3.481
		Diameter (in)=	3.924	3.919	3.906			
		Height (in)=	4.487	4.502	4.491			
	After 42 hrs oven dried at 71°C	Mass (gm)=	1310.630			53.697	1282.850	1284.760
		Mass (lb)=	2.889				2.828	2.832
		Diameter (in)=	3.907	3.906	3.904			
		Height (in)=	4.483	4.488	4.475			
	After giving firm strokes	Mass (gm)=					1277.850	1279.770
		Mass (lb)=					2.817	2.821
End of 4th Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 5	After 5 hrs immersion	Mass (gm)=	1602.160			53.991	1569.060	1580.120
		Mass (lb)=	3.532				3.459	3.484
		Diameter (in)=	3.915	3.916	3.908			
		Height (in)=	4.488	4.493	4.488			
	After 42 hrs oven dried at 71°C	Mass (gm)=	1312.970			53.655	1279.000	1284.000
		Mass (lb)=	2.895				2.820	2.831
		Diameter (in)=	3.908	3.907	3.907			
		Height (in)=	4.470	4.479	4.475			
	After giving firm strokes	Mass (gm)=					1281.590	1275.260
		Mass (lb)=					2.825	2.811
End of 5th Cycle								
Cycle 6	After 5 hrs immersion	Mass (gm)=	1601.740			53.937	1467.220	1575.700
		Mass (lb)=	3.531				3.235	3.474
		Diameter (in)=	3.915	3.909	3.906			
		Height (in)=	4.491	4.493	4.492			
	After 42 hrs oven dried at 71°C	Mass (gm)=	1314.420			53.569	1276.530	1275.230
		Mass (lb)=	2.898				2.814	2.811
		Diameter (in)=	3.901	3.900	3.902			
		Height (in)=	4.483	4.492	4.471			
	After giving firm strokes	Mass (gm)=					1270.380	1271.040
		Mass (lb)=					2.801	2.802
End of 6th Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 7	After 5 hrs immersion	Mass (gm)=	1603.170			53.997	1559.970	1569.530
		Mass (lb)=	3.534				3.439	3.460
		Diameter (in)=	3.912	3.917	3.908			
		Height (in)=	4.491	4.486	4.498			
	After 42 hrs oven dried at 71°C	Mass (gm)=	1314.420			53.550	1267.950	1264.540
		Mass (lb)=	2.898				2.795	2.788
		Diameter (in)=	3.905	3.900	3.902			
		Height (in)=	4.477	4.476	4.479			
	After giving firm strokes	Mass (gm)=					1261.360	1258.900
		Mass (lb)=					2.781	2.775
End of 7th Cycle								
Cycle 8	After 5 hrs immersion	Mass (gm)=	1604.560			54.055	1553.640	1563.700
		Mass (lb)=	3.537				3.425	3.447
		Diameter (in)=	3.912	3.913	3.917			
		Height (in)=	4.484	4.489	4.505			
	After 42 hrs oven dried at 71°C	Mass (gm)=	1305.280			53.649	1256.740	1259.330
		Mass (lb)=	2.878				2.771	2.776
		Diameter (in)=	3.909	3.907	3.904			
		Height (in)=	4.476	4.470	4.481			
	After giving firm strokes	Mass (gm)=					1252.040	1253.420
		Mass (lb)=					2.760	2.763
End of 8th Cycle								

<table>
<tr><td rowspan="2">Cycles</td><td rowspan="2">Procedure</td><td>Sample No.</td><td colspan="4">Sample 1</td><td>Sample 2</td><td>Sample 3</td></tr>
<tr><td>Parameter</td><td colspan="3">Mass/diameter/height</td><td>Avg. Vol. in^3</td><td>Mass</td><td>Mass</td></tr>
<tr><td rowspan="10">Cycle 9</td><td rowspan="4">After 5 hrs immersion</td><td>Mass (gm)=</td><td colspan="3">1606.090</td><td rowspan="4">53.999</td><td>1549.080</td><td>1556.140</td></tr>
<tr><td>Mass (lb)=</td><td colspan="3">3.541</td><td>3.415</td><td>3.431</td></tr>
<tr><td>Diameter (in)=</td><td>3.915</td><td>3.915</td><td>3.905</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Height (in)=</td><td>4.487</td><td>4.489</td><td>4.504</td></tr>
<tr><td rowspan="4">After 42 hrs oven dried at 71^oC</td><td>Mass (gm)=</td><td colspan="3">1300.700</td><td rowspan="4">53.729</td><td>1251.470</td><td>1250.780</td></tr>
<tr><td>Mass (lb)=</td><td colspan="3">2.868</td><td>2.759</td><td>2.757</td></tr>
<tr><td>Diameter (in)=</td><td>3.910</td><td>3.904</td><td>3.906</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Height (in)=</td><td>4.483</td><td>4.489</td><td>4.475</td></tr>
<tr><td rowspan="2">After giving firm strokes</td><td>Mass (gm)=</td><td colspan="4" rowspan="2"></td><td>1248.490</td><td>1248.250</td></tr>
<tr><td>Mass (lb)=</td><td>2.752</td><td>2.752</td></tr>
<tr><td colspan="9">End of 9th Cycle</td></tr>
<tr><td rowspan="10">Cycle 10</td><td rowspan="4">After 5 hrs immersion</td><td>Mass (gm)=</td><td colspan="3">1605.980</td><td rowspan="4">54.048</td><td>1546.590</td><td>1552.180</td></tr>
<tr><td>Mass (lb)=</td><td colspan="3">3.541</td><td>3.410</td><td>3.422</td></tr>
<tr><td>Diameter (in)=</td><td>3.913</td><td>3.918</td><td>3.915</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Height (in)=</td><td>4.486</td><td>4.489</td><td>4.492</td></tr>
<tr><td rowspan="4">After 42 hrs oven dried at 71^oC</td><td>Mass (gm)=</td><td colspan="3">1304.050</td><td rowspan="4">53.671</td><td>1243.950</td><td>1247.590</td></tr>
<tr><td>Mass (lb)=</td><td colspan="3">2.875</td><td>2.742</td><td>2.750</td></tr>
<tr><td>Diameter (in)=</td><td>3.909</td><td>3.909</td><td>3.904</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Height (in)=</td><td>4.487</td><td>4.476</td><td>4.465</td></tr>
<tr><td rowspan="2">After giving firm strokes</td><td>Mass (gm)=</td><td colspan="4" rowspan="2"></td><td>1237.570</td><td>1241.760</td></tr>
<tr><td>Mass (lb)=</td><td>2.728</td><td>2.738</td></tr>
<tr><td colspan="9">End of 10th Cycle</td></tr>
</table>

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 11	After 5 hrs immersion	Mass (gm)=	1606.002			53.982	1540.140	1544.700
		Mass (lb)=	3.541				3.395	3.405
		Diameter (in)=	3.915	3.915	3.911			
		Height (in)=	4.49	4.499	4.473			
	After 42 hrs oven dried at 71°C	Mass (gm)=	1304.120			53.654	1236.340	1240.700
		Mass (lb)=	2.875				2.726	2.735
		Diameter (in)=	3.907	3.911	3.903			
		Height (in)=	4.483	4.475	4.468			
	After giving firm strokes	Mass (gm)=					1230.370	1234.510
		Mass (lb)=					2.712	2.722
End of 11th Cycle								
Cycle 12	After 5 hrs immersion	Mass (gm)=	1608.790			53.861	1532.280	1536.590
		Mass (lb)=	3.547				3.378	3.388
		Diameter (in)=	3.914	3.913	3.91			
		Height (in)=	4.482	4.478	4.481			
	After 42 hrs oven dried at 71°C	Mass (gm)=	1296.570			53.633	1226.390	1228.080
		Mass (lb)=	2.858				2.704	2.707
		Diameter (in)=	3.901	3.912	3.904			
		Height (in)=	4.482	4.481	4.467			
	After giving firm strokes	Mass (gm)=					1221.380	1223.190
		Mass (lb)=					2.693	2.697
End of 12th Cycle								
Final	Oven dried at 110°C	Mass (gm)=	1238.330			53.434	1170.170	1169.870
		Mass (lb)=	2.730				2.580	2.579
		Diameter (in)=	3.904	3.905	3.894			
		Height (in)=	4.476	4.464	4.472			

Percent Loss of Soil Calculation for WD_10C_0.5F

Mass/Sample	Sample 1	Sample 2	Sample 3
Original Calculated Dry Mass (gm)	1215.995	1209.864	1207.509
Final Oven Dried Mass (gm)	1238.330	1170.170	1169.870
Mass of water of Hydration (%)	3.500		
Corrected Oven Dry Mass (gm)	1196.454	1130.599	1130.309
Soil-Cement loss (%)	1.607	6.552	6.393

Compressive Strength Calculation for WD_10C_0.5F

Samples	Load (lb)	Area (in^2)	Min. CS (psi)	Test time
Sample 1	16690	11.952	1396.415	After 12 cycle
Sample 2	12615	11.684	1079.688	After 12 cycle
Sample 3	13400	11.617	1153.444	After 12 cycle

APPENDIX F

FREEZING-THAWING TEST

Test F-1 Freezing-Thawing Test Data of EPK Clay (FT_0C)

Molding Data (FT_0C)

Test Start Date: 1/16/2019

For each sample:

OMC=	35.000	%
MDD=	83.800	lb/ft^3
Soil=	1400.000	gm
Cement=	0.000	gm
Fiber=	0.000	gm
Total Soil + Cement + Fiber=	1400.000	gm
Water=	490.000	gm
Volume of mold (ft^3)=	0.033	ft^3
Volume of mold (cc)=	943.895	cc
1 gm/cc=	62.428	lb/ft3

Sample No.	Sample 1	Sample 2	Sample 3
Mass of mold (gm)=	2027.600	2027.600	2027.600
Mass of mold + compacted specimen (gm)=	3733.350	3725.930	3732.620
Mass of compacted specimen (gm)=	1705.750	1698.330	1705.020
Moist density of compacted specimen (gm/cc) =	1.807	1.799	1.806

Molding Data Continue (FT_0C)

Sample No.	Sample 1		Sample 2		Sample 3	
Moisture Can No.	1	2	3	4	5	6
Mass of Moisture Can (gm)	29.970	29.710	30.540	30.450	30.250	30.610
Mass of Can + Moist Soil (gm)	108.380	117.090	109.690	109.510	110.980	88.740
Mass of Can + Dry Soil (gm)	88.310	94.990	89.350	89.360	90.620	73.890
Moisture Content (%)	34.402	33.854	34.586	34.205	33.725	34.311
Average Moisture Content (%)	34.128		34.395		34.018	
Dry Unit Mass of Compaction (gm/cc)	1.347		1.339		1.348	
Dry Unit Mass of Compaction (lb/ft^3)	84.111		83.578		84.144	
Difference in MC and OMC (%)	0.872		0.605		0.982	
Difference in dry density and MDD (lb/ft^3)	0.311		0.222		0.344	

Difference between OMC and moisture content of specimen < 1%, OK
Difference between MDD and dry density of specimen < 3 lb/ft^3, OK

Initial Procedure	Sample No.	Sample 1				Sample 2	Sample 3
	Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
After Molding Date: 10/06/2018	Mass (gm)=	1704.680			57.786	1697.690	1704.380
	Mass (lb)=	3.758				3.743	3.758
	Diameter (in)=	3.992	3.999	3.994			
	Height (in)=	4.606	4.622	4.602			
After 7 days storage period	Mass (gm)=	1702.390			57.696	1696.820	1703.530
	Mass (lb)=	3.753				3.741	3.756
	Diameter (in)=	3.990	3.999	3.997			
	Height (in)=	4.602	4.608	4.596			
Original Dry Mass (gm)		**1269.228**				**1262.559**	**1271.116**
Original Dry Mass (lb)		**2.798**				**2.783**	**2.802**

Freezing-Thawing Cycle Data of EPK clay Sample (FT_0C)

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 1	After 24 hrs. freezing at -23°C	Mass (gm)=	1683.670			57.614	1676.970	1686.970
		Mass (lb)=	3.712				3.697	3.719
		Diameter (in)=	3.947	3.977	3.998			
		Height (in)=	4.668	4.620	4.647			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1702.900			57.730	1696.600	1688.700
		Mass (lb)=	3.754				3.740	3.723
		Diameter (in)=	3.986	3.976	3.993			
		Height (in)=	4.605	4.618	4.663			
	After giving firm strokes	Mass (gm)=					1533.890	1659.240
		Mass (lb)=					3.382	3.658
End of 1st Cycle								
Cycle 2	After 24 hrs. freezing at -23°C	Mass (gm)=	1676.870			62.253	1521.350	1642.450
		Mass (lb)=	3.697				3.354	3.621
		Diameter (in)=	4.088	4.073	4.069			
		Height (in)=	4.766	4.818	4.724			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1668.780			56.998	1511.960	1636.170
		Mass (lb)=	3.679				3.333	3.607
		Diameter (in)=	3.991	3.949	3.969			
		Height (in)=	4.642	4.588	4.586			
	After giving firm strokes	Mass (gm)=					785.740	1506.050
		Mass (lb)=					1.732	3.320
All samples collapsed after cycle 2								

Test F-2 Freezing-Thawing Test Data of EPK Clay + 5% Cement (FT_5C)

Molding Data (FT_5C)

Test Start Date: 1/30/2019

For each sample:

OMC=	36.500	%
MDD=	80.300	lb/ft^3
Soil=	1300.000	gm
Cement=	65.000	gm
Fiber=	0.000	gm
Total Soil + Cement + Fiber=	1365.000	gm
Water=	498.225	gm
Volume of mold (ft^3)=	0.033	ft^3
Volume of mold (cc)=	943.895	cc
1 gm/cc=	62.428	lb/ft3

Sample No.	Sample 1	Sample 2	Sample 3
Mass of mold (gm)=	2034.600	2034.600	2034.600
Mass of mold + compacted specimen (gm)=	3684.410	3650.060	3641.920
Mass of compacted specimen (gm)=	1649.810	1615.460	1607.320
Moist density of compacted specimen (gm/cc) =	1.748	1.711	1.703

Molding Data Continue (FT_5C)

Sample No.	Sample 1		Sample 2		Sample 3	
Moisture Can No.	1	2	3	4	5	6
Mass of Moisture Can (gm)	29.970	29.710	30.540	30.470	30.250	30.610
Mass of Can + Moist Soil (gm)	116.810	118.020	117.690	107.560	132.430	114.130
Mass of Can + Dry Soil (gm)	93.520	94.930	94.350	87.080	105.080	92.020
Moisture Content (%)	36.648	35.403	36.577	36.177	36.550	36.004
Average Moisture Content (%)	36.026		36.377		36.277	
Dry Unit Mass of Compaction (gm/cc)	1.285		1.255		1.250	
Dry Unit Mass of Compaction (lb/ft^3)	80.217		78.345		78.008	
Difference in MC and OMC (%)	0.474		0.123		0.223	
Difference in dry density and MDD (lb/ft^3)	0.083		1.955		2.292	

Difference between OMC and moisture content of specimen < 1%, OK

Difference between MDD and dry density of specimen < 3 lb/ft^3, OK

Initial Procedure	Sample No.	Sample 1				Sample 2	Sample 3
	Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
After Molding Date: 10/06/2018	Mass (gm)=	1648.940			57.353	1614.430	1606.240
	Mass (lb)=	3.635				3.559	3.541
	Diameter (in)=	3.993	3.987	3.986			
	Height (in)=	4.584	4.597	4.589			
After 7 days storage period	Mass (gm)=	1647.420			57.127	1613.850	1604.810
	Mass (lb)=	3.632				3.558	3.538
	Diameter (in)=	3.988	3.977	3.983			
	Height (in)=	4.578	4.593	4.586			
Original Dry Mass (gm)		**1211.109**				**1183.371**	**1177.611**
Original Dry Mass (lb)		**2.670**				**2.609**	**2.596**

Freezing-Thawing Cycle Data of EPK clay + 5% Cement (FT_5C)

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 1	After 24 hrs. freezing at -23^{o}C	Mass (gm)=	1632.320			57.230	1597.610	1588.540
		Mass (lb)=	3.599				3.522	3.502
		Diameter (in)=	3.979	3.979	3.983			
		Height (in)=	4.597	4.601	4.600			
	After 23 hrs. thawing at 23^{o}C and 100% relative humidity	Mass (gm)=	1665.470			58.156	1622.510	1638.730
		Mass (lb)=	3.672				3.577	3.613
		Diameter (in)=	3.980	4.012	4.017			
		Height (in)=	4.614	4.616	4.633			
	After giving firm strokes	Mass (gm)=					1602.940	1496.570
		Mass (lb)=					3.534	3.299
End of 1st Cycle								
Cycle 2	After 24 hrs. freezing at -23^{o}C	Mass (gm)=	1635.920			60.083	1590.900	1484.430
		Mass (lb)=	3.607				3.507	3.273
		Diameter (in)=	4.048	4.028	4.005			
		Height (in)=	4.763	4.691	4.698			
	After 23 hrs. thawing at 23^{o}C and 100% relative humidity	Mass (gm)=	1656.520			59.028	1622.510	1638.730
		Mass (lb)=	3.652				3.577	3.613
		Diameter (in)=	4.032	4.038	4.006			
		Height (in)=	4.646	4.653	4.616			
	After giving firm strokes	Mass (gm)=					1602.940	1496.570
		Mass (lb)=					3.534	3.299
End of 2nd Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 3	After 24 hrs. freezing at -23°C	Mass (gm)=	1613.540			59.198	1537.430	899.780
		Mass (lb)=	3.557				3.389	1.984
		Diameter (in)=	3.999	4.018	4.050			
		Height (in)=	4.652	4.687	4.637			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1545.980			56.769	1569.480	918.220
		Mass (lb)=	3.408				3.460	2.024
		Diameter (in)=	4.015	3.998	4.009			
		Height (in)=	4.439	4.434	4.630			
	After giving firm strokes	Mass (gm)=					1529.600	Collapsed
		Mass (lb)=					3.372	
End of 3rd Cycle								
Cycle 4	After 24 hrs. freezing at -23°C	Mass (gm)=	1446.250			57.757	1513.990	
		Mass (lb)=	3.188				3.338	
		Diameter (in)=	4.024	4.007	4.005			
		Height (in)=	4.473	4.604	4.629			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	Collapsed				1525.710	
		Mass (lb)=					3.364	
		Diameter (in)=						
		Height (in)=						
	After giving firm strokes	Mass (gm)=					1490.560	
		Mass (lb)=					3.286	
End of 4th Cycle								
Final	Oven dried at 110°C	Mass (gm)=					986.670	
		Mass (lb)=					2.175	
		Diameter (in)=						
		Height (in)=						

Test F-3 Freezing-Thawing Test Data of EPK Clay + 10% Cement (FT_10C)

Molding Data (FT_10C)

Test Start Date: 1/30/2019

For each sample:

OMC=	36.000	%
MDD=	81.800	lb/ft^3
Soil=	1300.000	gm
Cement=	130.000	gm
Fiber=	0.000	gm
Total Soil + Cement + Fiber=	1430.000	gm
Water=	514.800	gm
Volume of mold (ft^3)=	0.033	ft^3
Volume of mold (cc)=	943.895	cc
1 gm/cc=	62.428	lb/ft3

Sample No.	Sample 1	Sample 2	Sample 3
Mass of mold (gm)=	2027.460	2027.460	2027.460
Mass of mold + compacted specimen (gm)=	3702.630	3698.610	3684.820
Mass of compacted specimen (gm)=	1675.170	1671.150	1657.360
Moist density of compacted specimen (gm/cc) =	1.775	1.770	1.756

Molding Data Continue (FT_10C)

Sample No.	Sample 1		Sample 2		Sample 3	
Moisture Can No.	1	2	3	4	5	6
Mass of Moisture Can (gm)	29.950	29.690	30.540	30.450	30.250	30.610
Mass of Can + Moist Soil (gm)	109.680	65.410	120.930	93.900	134.240	81.480
Mass of Can + Dry Soil (gm)	88.360	55.990	97.140	77.200	106.510	68.060
Moisture Content (%)	36.501	35.817	35.721	35.722	36.362	35.834
Average Moisture Content (%)	36.159		35.721		36.098	
Dry Unit Mass of Compaction (gm/cc)	1.303		1.304		1.290	
Dry Unit Mass of Compaction (lb/ft^3)	81.371		81.437		80.541	
Difference in MC and OMC (%)	0.159		0.279		0.098	
Difference in dry density and MDD (lb/ft^3)	0.429		0.363		1.259	

Difference between OMC and moisture content of specimen < 1%, OK

Difference between MDD and dry density of specimen < 3 lb/ft^3, OK

Initial Procedure	Sample No.	Sample 1				Sample 2	Sample 3
	Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
After Molding Date: 10/06/2018	Mass (gm)=	1673.890			56.499	1670.100	1656.170
	Mass (lb)=	3.690				3.682	3.651
	Diameter (in)=	3.971	3.975	3.970			
	Height (in)=	4.559	4.570	4.550			
After 7 days storage period	Mass (gm)=	1673.290			56.586	1669.440	1655.860
	Mass (lb)=	3.689				3.680	3.651
	Diameter (in)=	3.973	3.971	3.972			
	Height (in)=	4.567	4.559	4.574			
Original Dry Mass (gm)		**1228.923**				**1230.050**	**1216.663**
Original Dry Mass (lb)		**2.709**				**2.712**	**2.682**

Freezing-Thawing Cycle Data of EPK clay + 10% Cement (FT_10C)

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 1	After 24 hrs. freezing at -23°C	Mass (gm)=	1654.530			56.769	1650.570	1637.100
		Mass (lb)=	3.648				3.639	3.609
		Diameter (in)=	3.979	3.979	3.972			
		Height (in)=	4.560	4.585	4.567			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1665.390			57.055	1656.100	1647.620
		Mass (lb)=	3.672				3.651	3.632
		Diameter (in)=	3.972	3.981	3.981			
		Height (in)=	4.632	4.578	4.562			
	After giving firm strokes	Mass (gm)=					1645.980	1638.330
		Mass (lb)=					3.629	3.612
End of 1st Cycle								
Cycle 2	After 24 hrs. freezing at -23°C	Mass (gm)=	1645.740			57.038	1631.670	1624.530
		Mass (lb)=	3.628				3.597	3.581
		Diameter (in)=	3.977	3.973	3.964			
		Height (in)=	4.604	4.638	4.572			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1651.000			56.268	1642.150	1628.390
		Mass (lb)=	3.640				3.620	3.590
		Diameter (in)=	3.962	3.965	3.972			
		Height (in)=	4.580	4.553	4.529			
	After giving firm strokes	Mass (gm)=					1632.630	1617.920
		Mass (lb)=					3.599	3.567
End of 2nd Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 3	After 24 hrs. freezing at -23^{o}C	Mass (gm)=	1630.090			55.934	1617.150	1602.250
		Mass (lb)=	3.594				3.565	3.532
		Diameter (in)=	3.955	3.964	3.973			
		Height (in)=	4.526	4.545	4.526			
	After 23 hrs. thawing at 23^{o}C and 100% relative humidity	Mass (gm)=	1643.150			56.147	1622.180	1615.630
		Mass (lb)=	3.623				3.576	3.562
		Diameter (in)=	3.961	3.958	3.965			
		Height (in)=	4.598	4.541	4.528			
	After giving firm strokes	Mass (gm)=					1610.450	1601.020
		Mass (lb)=					3.550	3.530
End of 3rd Cycle								
Cycle 4	After 24 hrs. freezing at -23^{o}C	Mass (gm)=	1620.110			55.839	1591.740	1583.260
		Mass (lb)=	3.572				3.509	3.490
		Diameter (in)=	3.950	3.954	3.980			
		Height (in)=	4.527	4.520	4.545			
	After 23 hrs. thawing at 23^{o}C and 100% relative humidity	Mass (gm)=	1622.330			55.651	1597.120	1585.290
		Mass (lb)=	3.577				3.521	3.495
		Diameter (in)=	3.953	3.952	3.952			
		Height (in)=	4.545	4.526	4.537			
	After giving firm strokes	Mass (gm)=					1588.770	1578.940
		Mass (lb)=					3.503	3.481
End of 4th Cycle								

Cycles	Procedure	Sample No. / Parameter	Sample 1 Mass/diameter/height			Sample 1 Avg. Vol. in^3	Sample 2 Mass	Sample 3 Mass
Cycle 5	After 24 hrs. freezing at -23°C	Mass (gm)=	1602.350			55.451	1571.500	1561.750
		Mass (lb)=	3.533				3.465	3.443
		Diameter (in)=	3.943	3.948	3.946			
		Height (in)=	4.523	4.558	4.524			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1624.210			55.671	1582.250	1565.440
		Mass (lb)=	3.581				3.488	3.451
		Diameter (in)=	3.948	3.956	3.963			
		Height (in)=	4.527	4.537	4.526			
	After giving firm strokes	Mass (gm)=					1568.940	1552.420
		Mass (lb)=					3.459	3.422
End of 5th Cycle								
Cycle 6	After 24 hrs. freezing at -23°C	Mass (gm)=	1603.560			56.102	1554.690	1537.260
		Mass (lb)=	3.535				3.428	3.389
		Diameter (in)=	3.952	3.952	3.948			
		Height (in)=	4.558	4.611	4.561			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1609.050			55.398	1575.240	1554.170
		Mass (lb)=	3.547				3.473	3.426
		Diameter (in)=	3.949	3.946	3.949			
		Height (in)=	4.519	4.535	4.522			
	After giving firm strokes	Mass (gm)=					1568.330	1541.480
		Mass (lb)=					3.458	3.398
End of 6th Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 7	After 24 hrs. freezing at -23^{o}C	Mass (gm)=	1590.200			55.225	1570.770	1526.560
		Mass (lb)=	3.506				3.463	3.365
		Diameter (in)=	3.945	3.948	3.943			
		Height (in)=	4.518	4.509	4.525			
	After 23 hrs. thawing at 23^{o}C and 100% relative humidity	Mass (gm)=	1610.960			55.269	1574.130	1539.570
		Mass (lb)=	3.552				3.470	3.394
		Diameter (in)=	3.945	3.943	3.940			
		Height (in)=	4.538	4.510	4.533			
	After giving firm strokes	Mass (gm)=					1560.500	1527.980
		Mass (lb)=					3.440	3.369
End of 7th Cycle								
Cycle 8	After 24 hrs. freezing at -23^{o}C	Mass (gm)=	1592.860			55.260	1545.590	1515.660
		Mass (lb)=	3.512				3.407	3.341
		Diameter (in)=	3.942	3.945	3.934			
		Height (in)=	4.517	4.528	4.550			
	After 23 hrs. thawing at 23^{o}C and 100% relative humidity	Mass (gm)=	1625.940			55.590	1561.110	1520.520
		Mass (lb)=	3.585				3.442	3.352
		Diameter (in)=	3.946	3.955	3.960			
		Height (in)=	4.537	4.515	4.532			
	After giving firm strokes	Mass (gm)=					1554.020	1513.760
		Mass (lb)=					3.426	3.337
End of 8th Cycle								

<table>
<tr><td rowspan="2">Cycles</td><td rowspan="2">Procedure</td><td>Sample No.</td><td colspan="4">Sample 1</td><td>Sample 2</td><td>Sample 3</td></tr>
<tr><td>Parameter</td><td colspan="3">Mass/diameter/height</td><td>Avg. Vol. in^3</td><td>Mass</td><td>Mass</td></tr>
<tr><td rowspan="10">Cycle 9</td><td rowspan="4">After 24 hrs. freezing at -23^{o}C</td><td>Mass (gm)=</td><td colspan="3">1611.260</td><td rowspan="4">55.434</td><td>1539.980</td><td>1501.430</td></tr>
<tr><td>Mass (lb)=</td><td colspan="3">3.552</td><td>3.395</td><td>3.310</td></tr>
<tr><td>Diameter (in)=</td><td>3.946</td><td>3.950</td><td>3.947</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Height (in)=</td><td>4.527</td><td>4.539</td><td>4.521</td></tr>
<tr><td rowspan="4">After 23 hrs. thawing at 23^{o}C and 100% relative humidity</td><td>Mass (gm)=</td><td colspan="3">1620.310</td><td rowspan="4">55.441</td><td>1574.700</td><td>1506.790</td></tr>
<tr><td>Mass (lb)=</td><td colspan="3">3.572</td><td>3.472</td><td>3.322</td></tr>
<tr><td>Diameter (in)=</td><td>3.952</td><td>3.948</td><td>3.942</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Height (in)=</td><td>4.537</td><td>4.523</td><td>4.531</td></tr>
<tr><td rowspan="2">After giving firm strokes</td><td>Mass (gm)=</td><td colspan="4" rowspan="2"></td><td>1561.750</td><td>1495.600</td></tr>
<tr><td>Mass (lb)=</td><td>3.443</td><td>3.297</td></tr>
<tr><td colspan="9">End of 9th Cycle</td></tr>
<tr><td rowspan="10">Cycle 10</td><td rowspan="4">After 24 hrs. freezing at -23^{o}C</td><td>Mass (gm)=</td><td colspan="3">1602.820</td><td rowspan="4">55.173</td><td>1546.960</td><td>1483.010</td></tr>
<tr><td>Mass (lb)=</td><td colspan="3">3.534</td><td>3.410</td><td>3.269</td></tr>
<tr><td>Diameter (in)=</td><td>3.946</td><td>3.944</td><td>3.936</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Height (in)=</td><td>4.528</td><td>4.514</td><td>4.520</td></tr>
<tr><td rowspan="4">After 23 hrs. thawing at 23^{o}C and 100% relative humidity</td><td>Mass (gm)=</td><td colspan="3">1608.900</td><td rowspan="4">55.149</td><td>1561.570</td><td>1500.720</td></tr>
<tr><td>Mass (lb)=</td><td colspan="3">3.547</td><td>3.443</td><td>3.309</td></tr>
<tr><td>Diameter (in)=</td><td>3.944</td><td>3.941</td><td>3.945</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Height (in)=</td><td>4.513</td><td>4.510</td><td>4.524</td></tr>
<tr><td rowspan="2">After giving firm strokes</td><td>Mass (gm)=</td><td colspan="4" rowspan="2"></td><td>1553.770</td><td>1494.090</td></tr>
<tr><td>Mass (lb)=</td><td>3.425</td><td>3.294</td></tr>
<tr><td colspan="9">End of 10th Cycle</td></tr>
</table>

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 11	After 24 hrs. freezing at -23°C	Mass (gm)=	1595.620			55.430	1538.200	1480.250
		Mass (lb)=	3.518				3.391	3.263
		Diameter (in)=	3.936	3.949	3.945			
		Height (in)=	4.579	4.526	4.511			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1635.360			55.740	1544.930	1493.940
		Mass (lb)=	3.605				3.406	3.294
		Diameter (in)=	3.948	3.956	3.956			
		Height (in)=	4.558	4.520	4.545			
	After giving firm strokes	Mass (gm)=					1537.790	1487.320
		Mass (lb)=					3.390	3.279
End of 11th Cycle								
Cycle 12	After 24 hrs. freezing at -23°C	Mass (gm)=	1616.840			55.718	1523.540	1473.630
		Mass (lb)=	3.565				3.359	3.249
		Diameter (in)=	3.949	3.969	3.941			
		Height (in)=	4.544	4.535	4.541			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1627.430			55.687	1536.800	1488.840
		Mass (lb)=	3.588				3.388	3.282
		Diameter (in)=	3.950	3.950	3.943			
		Height (in)=	4.540	4.552	4.557			
	After giving firm strokes	Mass (gm)=					1524.170	1475.340
		Mass (lb)=					3.360	3.253
End of 12th Cycle								
Final	Oven dried at 110°C	Mass (gm)=	1295.760			53.992	1206.970	1195.700
		Mass (lb)=	2.857				2.661	2.636
		Diameter (in)=	3.901	3.906	3.913			
		Height (in)=	4.496	4.517	4.500			

Percent Loss of Soil Calculation for FT_10C

Mass/Sample	Sample 1	Sample 2	Sample 3
Original Calculated Dry Mass (gm)	1228.923	1230.050	1216.663
Final Oven Dried Mass (gm)	1295.760	1206.970	1195.700
Mass of water of Hydration (%)	5.440		
Corrected Oven Dry Mass (gm)	1228.907	1144.698	1134.010
Soil-Cement loss (%)	0.000	6.939	6.793

Compressive Strength Calculation for FT_10C

Samples	Load (lb)	Area (in^2)	CS (psi)	Test time
Sample 1	4767	11.964	398.436	After 12 cycle
Sample 2	4665	11.642	400.719	After 12 cycle
Sample 3	3016	11.467	263.019	After 12 cycle

Test F-4 Freezing-Thawing Test Data of EPK Clay + 5% Cement + 0.5% Fiber (FT_5C_0.5F)

Molding Data (FT_5C_0.5F)

Test Start Date: 3/1/2019

For each sample:

OMC=	37.000	%
MDD=	80.100	lb/ft^3
Soil=	1300.000	gm
Cement=	65.000	gm
Fiber=	6.500	gm
Total Soil + Cement + Fiber=	1371.500	gm
Water=	507.455	gm
Volume of mold (ft^3)=	0.033	ft^3
Volume of mold (cc)=	943.895	cc
1 gm/cc=	62.428	lb/ft3

Sample No.	Sample 1	Sample 2	Sample 3
Mass of mold (gm)=	2027.450	2027.450	2027.450
Mass of mold + compacted specimen (gm)=	3675.300	3689.440	3692.210
Mass of compacted specimen (gm)=	1647.850	1661.990	1664.760
Moist density of compacted specimen (gm/cc) =	1.746	1.761	1.764

Molding Data Continue (FT_5C_0.5F)

Sample No.	Sample 1		Sample 2		Sample 3	
Moisture Can No.	1	2	3	4	5	6
Mass of Moisture Can (gm)	29.970	29.710	30.530	30.450	30.240	30.610
Mass of Can + Moist Soil (gm)	114.110	118.210	110.270	101.330	107.400	110.670
Mass of Can + Dry Soil (gm)	91.990	94.540	89.020	82.490	87.050	89.280
Moisture Content (%)	35.666	36.511	36.331	36.203	35.821	36.458
Average Moisture Content (%)	36.088		36.267		36.140	
Dry Unit Mass of Compaction (gm/cc)	1.283		1.292		1.296	
Dry Unit Mass of Compaction (lb/ft^3)	80.085		80.667		80.877	
Difference in MC and OMC (%)	0.912		0.733		0.860	
Difference in dry density and MDD (lb/ft^3)	0.015		0.567		0.777	

Difference between OMC and moisture content of specimen < 1%, OK

Difference between MDD and dry density of specimen < 3 lb/ft^3, OK

Initial Procedure	Sample No.	Sample 1				Sample 2	Sample 3
	Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
After Molding Date: 10/06/2018	Mass (gm)=	1646.400			57.175	1660.840	1663.680
	Mass (lb)=	3.630				3.662	3.668
	Diameter (in)=	3.987	3.993	3.987			
	Height (in)=	4.579	4.576	4.570			
After 7 days storage period	Mass (gm)=	1645.060			57.211	1659.930	1661.870
	Mass (lb)=	3.627				3.660	3.664
	Diameter (in)=	3.981	3.992	3.996			
	Height (in)=	4.565	4.599	4.565			
Original Dry Mass (gm)		**1208.817**				**1218.146**	**1220.710**
Original Dry Mass (lb)		**2.665**				**2.686**	**2.691**

Freezing-Thawing Cycle Data of EPK clay + 5% Cement Sample + 0.5% Fiber (FT_5C_0.5F)

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 1	After 24 hrs. freezing at -23°C	Mass (gm)=	1625.020			56.834	1639.420	1642.330
		Mass (lb)=	3.583				3.614	3.621
		Diameter (in)=	3.986	3.981	3.976			
		Height (in)=	4.561	4.572	4.565			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1637.370			57.151	1649.650	1650.000
		Mass (lb)=	3.610				3.637	3.638
		Diameter (in)=	3.990	3.980	3.984			
		Height (in)=	4.604	4.577	4.568			
	After giving firm strokes	Mass (gm)=					1636.310	1636.730
		Mass (lb)=					3.607	3.608
End of 1st Cycle								
Cycle 2	After 24 hrs. freezing at -23°C	Mass (gm)=	1614.680			56.678	1617.860	1619.380
		Mass (lb)=	3.560				3.567	3.570
		Diameter (in)=	3.971	3.974	3.982			
		Height (in)=	4.571	4.558	4.568			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1626.720			56.295	1639.590	1634.720
		Mass (lb)=	3.586				3.615	3.604
		Diameter (in)=	3.966	3.968	3.967			
		Height (in)=	4.575	4.535	4.554			
	After giving firm strokes	Mass (gm)=					1625.950	1620.780
		Mass (lb)=					3.585	3.573
End of 2nd Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 3	After 24 hrs. freezing at -23°C	Mass (gm)=	1602.700			55.983	1607.190	1603.140
		Mass (lb)=	3.533				3.543	3.534
		Diameter (in)=	3.964	3.966	3.961			
		Height (in)=	4.549	4.524	4.538			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1610.730			55.901	1611.420	1608.320
		Mass (lb)=	3.551				3.553	3.546
		Diameter (in)=	3.958	3.957	3.946			
		Height (in)=	4.575	4.551	4.534			
	After giving firm strokes	Mass (gm)=					1603.840	1599.720
		Mass (lb)=					3.536	3.527
End of 3rd Cycle								
Cycle 4	After 24 hrs. freezing at -23°C	Mass (gm)=	1586.350			55.402	1588.790	1580.240
		Mass (lb)=	3.497				3.503	3.484
		Diameter (in)=	3.952	3.950	3.945			
		Height (in)=	4.528	4.525	4.517			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1593.550			55.410	1593.960	1590.170
		Mass (lb)=	3.513				3.514	3.506
		Diameter (in)=	3.942	3.940	3.948			
		Height (in)=	4.537	4.529	4.545			
	After giving firm strokes	Mass (gm)=					1582.660	1579.900
		Mass (lb)=					3.489	3.483
End of 4th Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 5	After 24 hrs. freezing at -23°C	Mass (gm)=	1572.110			55.265	1565.390	1563.200
		Mass (lb)=	3.466				3.451	3.446
		Diameter (in)=	3.941	3.941	3.936			
		Height (in)=	4.535	4.540	4.528			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1578.180			55.097	1608.570	1568.280
		Mass (lb)=	3.479				3.546	3.457
		Diameter (in)=	3.929	3.930	3.935			
		Height (in)=	4.534	4.545	4.538			
	After giving firm strokes	Mass (gm)=					1598.170	1559.580
		Mass (lb)=					3.523	3.438
End of 5th Cycle								
Cycle 6	After 24 hrs. freezing at -23°C	Mass (gm)=	1557.540			54.781	1579.770	1545.210
		Mass (lb)=	3.434				3.483	3.407
		Diameter (in)=	3.925	3.929	3.936			
		Height (in)=	4.520	4.519	4.509			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1559.541			54.900	1589.740	1545.210
		Mass (lb)=	3.438				3.505	3.407
		Diameter (in)=	3.924	3.925	3.933			
		Height (in)=	4.529	4.545	4.522			
	After giving firm strokes	Mass (gm)=					1577.100	1547.650
		Mass (lb)=					3.477	3.412
End of 6th Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 7	After 24 hrs. freezing at -23°C	Mass (gm)=	1534.770			54.652	1560.060	1531.150
		Mass (lb)=	3.384				3.439	3.376
		Diameter (in)=	3.922	3.920	3.922			
		Height (in)=	4.524	4.531	4.521			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1539.570			54.717	1568.800	1532.760
		Mass (lb)=	3.394				3.459	3.379
		Diameter (in)=	3.923	3.926	3.928			
		Height (in)=	4.539	4.507	4.516			
	After giving firm strokes	Mass (gm)=					1560.590	1524.000
		Mass (lb)=					3.441	3.360
End of 7th Cycle								
Cycle 8	After 24 hrs. freezing at -23°C	Mass (gm)=	1518.440			54.572	1544.500	1509.310
		Mass (lb)=	3.348				3.405	3.327
		Diameter (in)=	3.920	3.923	3.921			
		Height (in)=	4.516	4.522	4.518			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1533.090			54.612	1550.140	1522.720
		Mass (lb)=	3.380				3.417	3.357
		Diameter (in)=	3.917	3.921	3.926			
		Height (in)=	4.533	4.500	4.533			
	After giving firm strokes	Mass (gm)=					1540.800	1514.120
		Mass (lb)=					3.397	3.338
End of 8th Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 9	After 24 hrs. freezing at -23°C	Mass (gm)=	1515.440			54.728	1525.270	1499.880
		Mass (lb)=	3.341				3.363	3.307
		Diameter (in)=	3.921	3.922	3.930			
		Height (in)=	4.519	4.532	4.523			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1532.030			54.214	1555.310	1505.140
		Mass (lb)=	3.378				3.429	3.318
		Diameter (in)=	3.910	3.918	3.906			
		Height (in)=	4.510	4.514	4.512			
	After giving firm strokes	Mass (gm)=					1544.460	1495.380
		Mass (lb)=					3.405	3.297
End of 9th Cycle								
Cycle 10	After 24 hrs. freezing at -23°C	Mass (gm)=	1513.300			54.364	1530.430	1479.820
		Mass (lb)=	3.336				3.374	3.262
		Diameter (in)=	3.914	3.928	3.910			
		Height (in)=	4.495	4.522	4.515			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1521.080			54.671	1537.410	1491.450
		Mass (lb)=	3.353				3.389	3.288
		Diameter (in)=	3.915	3.936	3.925			
		Height (in)=	4.521	4.517	4.515			
	After giving firm strokes	Mass (gm)=					1528.240	1481.470
		Mass (lb)=					3.369	3.266
End of 10th Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 11	After 24 hrs. freezing at -23°C	Mass (gm)=	1503.150			54.446	1512.650	1467.410
		Mass (lb)=	3.314				3.335	3.235
		Diameter (in)=	3.921	3.920	3.916			
		Height (in)=	4.520	4.501	4.520			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1517.590			54.364	1535.540	1483.630
		Mass (lb)=	3.346				3.385	3.271
		Diameter (in)=	3.915	3.914	3.920			
		Height (in)=	4.503	4.517	4.519			
	After giving firm strokes	Mass (gm)=					1525.710	1475.530
		Mass (lb)=					3.364	3.253
End of 11th Cycle								
Cycle 12	After 24 hrs. freezing at -23°C	Mass (gm)=	1500.550			54.280	1509.480	1461.020
		Mass (lb)=	3.308				3.328	3.221
		Diameter (in)=	3.916	3.911	3.915			
		Height (in)=	4.517	4.512	4.505			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1544.910			54.662	1542.830	1483.820
		Mass (lb)=	3.406				3.401	3.271
		Diameter (in)=	3.917	3.926	3.926			
		Height (in)=	4.518	4.529	4.520			
	After giving firm strokes	Mass (gm)=					1534.300	1476.530
		Mass (lb)=					3.383	3.255
End of 12th Cycle								
Final	Oven dried at 110°C	Mass (gm)=	1226.270			53.766	1178.820	1181.730
		Mass (lb)=	2.703				2.599	2.605
		Diameter (in)=	3.899	3.903	3.906			
		Height (in)=	4.497	4.498	4.489			

Percent Loss of Soil Calculation for FT_5C_0.5F

Mass/Sample	Sample 1	Sample 2	Sample 3
Original Calculated Dry Mass (gm)	1208.817	1218.146	1220.710
Final Oven Dried Mass (gm)	1226.270	1178.820	1181.730
Mass of water of Hydration (%)	3.500		
Corrected Oven Dry Mass (gm)	1184.802	1138.957	1141.768
Soil-Cement loss (%)	1.987	6.501	6.467

Compressive Strength Calculation for FT_5C_0.5F

Samples	Load (lb)	Area (in^2)	CS (psi)	Test time
Sample 1	5450	11.964	455.522	After 12 cycle
Sample 2	5400	11.678	462.413	After 12 cycle
Sample 3	5887	11.545	509.918	After 12 cycle

Test F-5 Freezing-Thawing Test Data of EPK Clay + 10% Cement + 0.5% Fiber (FT_10C_0.5F)

Molding Data (FT_10C_0.5F)

Test Start Date: 3/3/2019

For each sample:

OMC=	36.500	%
MDD=	82.000	lb/ft^3
Soil=	1300.000	gm
Cement=	130.000	gm
Fiber=	6.500	gm
Total Soil + Cement + Fiber=	1436.500	gm
Water=	524.323	gm
Volume of mold (ft^3)=	0.033	ft^3
Volume of mold (cc)=	943.895	cc
1 gm/cc=	62.428	lb/ft3

Sample No.	Sample 1	Sample 2	Sample 3
Mass of mold (gm)=	2027.600	2027.600	2027.600
Mass of mold + compacted specimen (gm)=	3696.400	3704.010	3688.890
Mass of compacted specimen (gm)=	1668.800	1676.410	1661.290
Moist density of compacted specimen (gm/cc) =	1.768	1.776	1.760

Molding Data Continue (FT_10C_0.5F)

Sample No.	Sample 1		Sample 2		Sample 3	
Moisture Can No.	1	2	3	4	5	6
Mass of Moisture Can (gm)	29.970	29.710	30.530	30.450	30.240	30.450
Mass of Can + Moist Soil (gm)	115.520	112.830	119.660	69.400	106.310	146.340
Mass of Can + Dry Soil (gm)	93.030	91.120	96.140	59.269	86.350	116.008
Moisture Content (%)	35.664	35.353	35.848	35.154	35.573	35.452
Average Moisture Content (%)	35.508		35.501		35.512	
Dry Unit Mass of Compaction (gm/cc)	1.305		1.311		1.299	
Dry Unit Mass of Compaction (lb/ft^3)	81.450		81.826		81.082	
Difference in MC and OMC (%)	0.992		0.999		0.988	
Difference in dry density and MDD (lb/ft^3)	0.550		0.174		0.918	

Difference between OMC and moisture content of specimen < 1%, OK

Difference between MDD and dry density of specimen < 3 lb/ft^3, OK

Initial Procedure	Sample No.	Sample 1				Sample 2	Sample 3
	Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
After Molding Date: 10/06/2018	Mass (gm)=	1667.360			57.165	1675.280	1660.120
	Mass (lb)=	3.676				3.693	3.660
	Diameter (in)=	3.994	3.993	3.996			
	Height (in)=	4.544	4.579	4.563			
After 7 days storage period	Mass (gm)=	1665.490			57.057	1674.580	1656.700
	Mass (lb)=	3.672				3.692	3.652
	Diameter (in)=	3.984	3.985	3.983			
	Height (in)=	4.564	4.568	4.599			
Original Dry Mass (gm)		**1229.067**				**1235.843**	**1222.544**
Original Dry Mass (lb)		**2.710**				**2.725**	**2.695**

Freezing-Thawing Cycle Data of EPK clay + 10% Cement Sample + 0.5% Fiber (FT_10C_0.5F)

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 1	After 24 hrs. freezing at -23^{o}C	Mass (gm)=	1643.810			56.611	1653.340	1639.910
		Mass (lb)=	3.624				3.645	3.615
		Diameter (in)=	3.978	3.987	3.975			
		Height (in)=	4.554	4.553	4.544			
	After 23 hrs. thawing at 23^{o}C and 100% relative humidity	Mass (gm)=	1650.850			56.441	1658.990	1641.290
		Mass (lb)=	3.639				3.657	3.618
		Diameter (in)=	3.978	3.994	3.979			
		Height (in)=	4.519	4.523	4.543			
	After giving firm strokes	Mass (gm)=					1648.410	1631.380
		Mass (lb)=					3.634	3.597
End of 1st Cycle								
Cycle 2	After 24 hrs. freezing at -23^{o}C	Mass (gm)=	1629.180			56.014	1632.650	1620.390
		Mass (lb)=	3.592				3.599	3.572
		Diameter (in)=	3.962	3.972	3.970			
		Height (in)=	4.540	4.523	4.526			
	After 23 hrs. thawing at 23^{o}C and 100% relative humidity	Mass (gm)=	1645.550			56.103	1635.640	1628.060
		Mass (lb)=	3.628				3.606	3.589
		Diameter (in)=	3.963	3.967	3.969			
		Height (in)=	4.512	4.561	4.549			
	After giving firm strokes	Mass (gm)=					1628.050	1619.700
		Mass (lb)=					3.589	3.571
End of 2nd Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 3	After 24 hrs. freezing at -23^{o}C	Mass (gm)=	1622.090			55.968	1610.910	1602.100
		Mass (lb)=	3.576				3.551	3.532
		Diameter (in)=	3.967	3.963	3.963			
		Height (in)=	4.542	4.536	4.525			
	After 23 hrs. thawing at 23^{o}C and 100% relative humidity	Mass (gm)=	1626.700			55.681	1621.170	1611.960
		Mass (lb)=	3.586				3.574	3.554
		Diameter (in)=	3.956	3.967	3.956			
		Height (in)=	4.527	4.527	4.511			
	After giving firm strokes	Mass (gm)=					1614.160	1605.510
		Mass (lb)=					3.559	3.540
End of 3rd Cycle								
Cycle 4	After 24 hrs. freezing at -23^{o}C	Mass (gm)=	1609.680			55.465	1598.860	1588.940
		Mass (lb)=	3.549				3.525	3.503
		Diameter (in)=	3.953	3.955	3.962			
		Height (in)=	4.509	4.511	4.513			
	After 23 hrs. thawing at 23^{o}C and 100% relative humidity	Mass (gm)=	1623.680			55.632	1604.360	1590.850
		Mass (lb)=	3.580				3.537	3.507
		Diameter (in)=	3.957	3.966	3.960			
		Height (in)=	4.525	4.513	4.506			
	After giving firm strokes	Mass (gm)=					1599.200	1585.800
		Mass (lb)=					3.526	3.496
End of 4th Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 5	After 24 hrs. freezing at -23°C	Mass (gm)=	1602.750			55.325	1582.800	1568.570
		Mass (lb)=	3.533				3.489	3.458
		Diameter (in)=	3.957	3.945	3.953			
		Height (in)=	4.513	4.502	4.518			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1619.450			55.875	1601.150	1582.240
		Mass (lb)=	3.570				3.530	3.488
		Diameter (in)=	3.963	3.961	3.963			
		Height (in)=	4.538	4.547	4.509			
	After giving firm strokes	Mass (gm)=					1589.030	1572.280
		Mass (lb)=					3.503	3.466
End of 5th Cycle								
Cycle 6	After 24 hrs. freezing at -23°C	Mass (gm)=	1593.590			55.451	1573.620	1555.980
		Mass (lb)=	3.513				3.469	3.430
		Diameter (in)=	3.951	3.958	3.952			
		Height (in)=	4.501	4.535	4.514			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1609.500			55.522	1593.630	1576.080
		Mass (lb)=	3.548				3.513	3.475
		Diameter (in)=	3.954	3.960	3.955			
		Height (in)=	4.504	4.532	4.513			
	After giving firm strokes	Mass (gm)=					1587.090	1570.150
		Mass (lb)=					3.499	3.462
End of 6th Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 7	After 24 hrs. freezing at -23^{o}C	Mass (gm)=	1587.940			55.454	1570.920	1554.630
		Mass (lb)=	3.501				3.463	3.427
		Diameter (in)=	3.952	3.951	3.954			
		Height (in)=	4.506	4.521	4.533			
	After 23 hrs. thawing at 23^{o}C and 100% relative humidity	Mass (gm)=	1607.430			55.765	1592.700	1570.730
		Mass (lb)=	3.544				3.511	3.463
		Diameter (in)=	3.963	3.955	3.956			
		Height (in)=	4.547	4.529	4.521			
	After giving firm strokes	Mass (gm)=					1585.310	1563.240
		Mass (lb)=					3.495	3.446
End of 7th Cycle								
Cycle 8	After 24 hrs. freezing at -23^{o}C	Mass (gm)=	1588.470			55.663	1570.890	1549.180
		Mass (lb)=	3.502				3.463	3.415
		Diameter (in)=	3.956	3.957	3.968			
		Height (in)=	4.533	4.498	4.525			
	After 23 hrs. thawing at 23^{o}C and 100% relative humidity	Mass (gm)=	1593.870			55.178	1599.620	1583.580
		Mass (lb)=	3.514				3.527	3.491
		Diameter (in)=	3.944	3.945	3.952			
		Height (in)=	4.523	4.513	4.493			
	After giving firm strokes	Mass (gm)=					1592.800	1577.120
		Mass (lb)=					3.512	3.477
End of 8th Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 9	After 24 hrs. freezing at -23^{o}C	Mass (gm)=	1573.810			55.257	1574.690	1559.380
		Mass (lb)=	3.470				3.472	3.438
		Diameter (in)=	3.947	3.949	3.953			
		Height (in)=	4.518	4.494	4.518			
	After 23 hrs. thawing at 23^{o}C and 100% relative humidity	Mass (gm)=	1586.010			55.408	1593.900	1575.410
		Mass (lb)=	3.497				3.514	3.473
		Diameter (in)=	3.951	3.956	3.949			
		Height (in)=	4.510	4.531	4.510			
	After giving firm strokes	Mass (gm)=					1585.950	1568.430
		Mass (lb)=					3.496	3.458
End of 9th Cycle								
Cycle 10	After 24 hrs. freezing at -23^{o}C	Mass (gm)=	1566.890			55.401	1570.420	1555.910
		Mass (lb)=	3.454				3.462	3.430
		Diameter (in)=	3.949	3.953	3.958			
		Height (in)=	4.495	4.528	4.517			
	After 23 hrs. thawing at 23^{o}C and 100% relative humidity	Mass (gm)=	1592.100			55.416	1594.230	1589.690
		Mass (lb)=	3.510				3.515	3.505
		Diameter (in)=	3.948	3.954	3.957			
		Height (in)=	4.520	4.497	4.529			
	After giving firm strokes	Mass (gm)=					1586.910	1581.820
		Mass (lb)=					3.499	3.487
End of 10th Cycle								

Cycles	Procedure	Sample No.	Sample 1				Sample 2	Sample 3
		Parameter	Mass/diameter/height			Avg. Vol. in^3	Mass	Mass
Cycle 11	After 24 hrs. freezing at -23°C	Mass (gm)=	1574.200			55.399	1564.560	1570.040
		Mass (lb)=	3.471				3.449	3.461
		Diameter (in)=	3.948	3.953	3.958			
		Height (in)=	4.527	4.516	4.499			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1586.960			55.483	1580.620	1575.870
		Mass (lb)=	3.499				3.485	3.474
		Diameter (in)=	3.954	3.959	3.951			
		Height (in)=	4.533	4.496	4.522			
	After giving firm strokes	Mass (gm)=					1573.530	1569.230
		Mass (lb)=					3.469	3.460
End of 11th Cycle								
Cycle 12	After 24 hrs. freezing at -23°C	Mass (gm)=	1569.730			55.286	1559.540	1554.760
		Mass (lb)=	3.461				3.438	3.428
		Diameter (in)=	3.946	3.951	3.949			
		Height (in)=	4.494	4.524	4.526			
	After 23 hrs. thawing at 23°C and 100% relative humidity	Mass (gm)=	1606.310			55.598	1581.270	1583.840
		Mass (lb)=	3.541				3.486	3.492
		Diameter (in)=	3.952	3.962	3.961			
		Height (in)=	4.532	4.523	4.499			
	After giving firm strokes	Mass (gm)=					1574.860	1572.420
		Mass (lb)=					3.472	3.467
End of 12th Cycle								
Final	Oven dried at 110°C	Mass (gm)=	1295.650			54.379	1253.210	1244.060
		Mass (lb)=	2.856				2.763	2.743
		Diameter (in)=	3.919	3.923	3.926			
		Height (in)=	4.501	4.506	4.492			

Percent Loss of Soil Calculation for FT_10C_0.5F

Mass/Sample	Sample 1	Sample 2	Sample 3
Original Calculated Dry Mass (gm)	1229.067	1235.843	1222.544
Final Oven Dried Mass (gm)	1295.650	1253.210	1244.060
Mass of water of Hydration (%)	5.420		
Corrected Oven Dry Mass (gm)	1229.036	1188.778	1180.099
Soil-Cement loss (%)	0.000	3.808	3.472

Compressive Strength Calculation for FT_10C_0.5F

Samples	Load (lb)	Area (in^2)	CS (psi)	Test time
Sample 1	6074	12.087	502.514	After 12 cycle
Sample 2	6362	11.757	541.136	After 12 cycle
Sample 3	6903	11.836	583.226	After 12 cycle

APPENDIX G

DURABILITY TEST PHOTOGRAPH

Figure F-1: Drying Temperature setup for Wetting-Drying Test

Figure F-2: Sample drying at 71°C

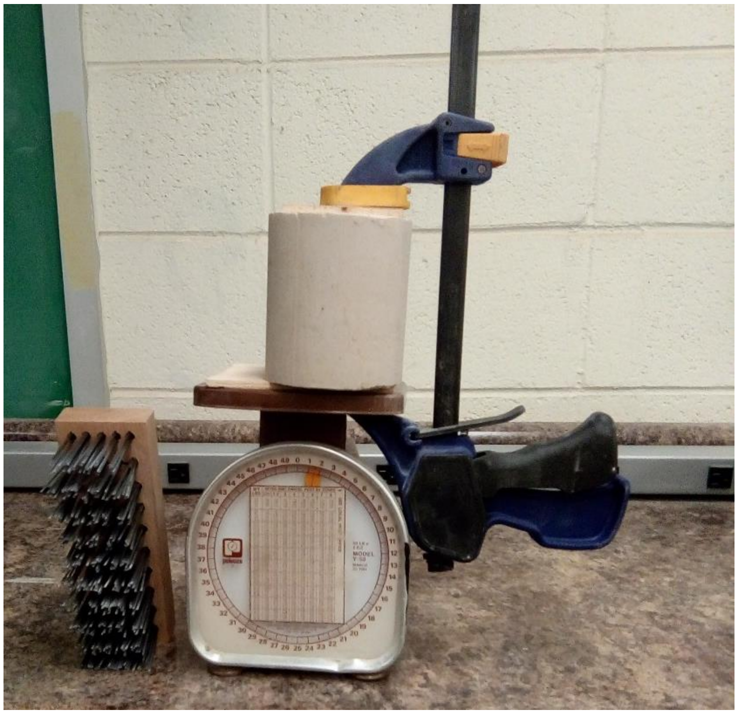

Figure F-3: Sample ready for Brushing

Figure F-4: Sample subjected to brushing

Figure F-5: Sample immersed in water during wetting process

Figure F-6: Samples inside freezing chamber during freezing process

Figure F-7: Samples after freezing

Figure F-8: Samples under thawing (inside humidity control chamber)

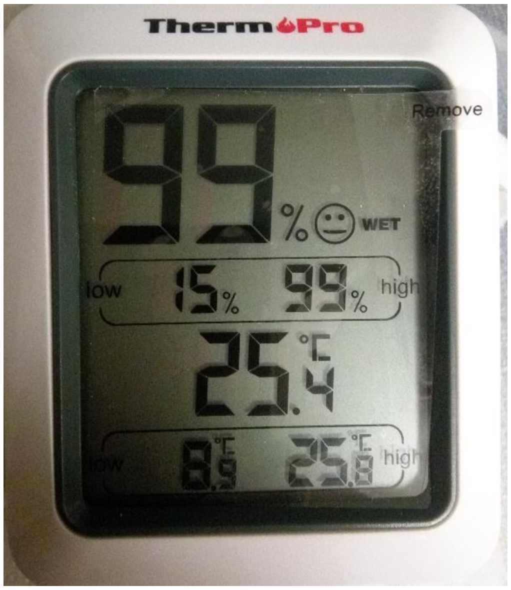

Figure F-9: Hygrometer reading inside humidity chamber

Figure F-10: EPK sample with cement only (without fiber)

crumbled completely during compression test

Figure F-11: EPK sample with cement + fiber during compression test, improves the brittle failure pattern

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Major Professor: Dr. Prabir K. Kolay