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Review on Soil Stabilization Techniques

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Abstract: Searching for the best soil stabilizers to overcome problems occur by the soft soils are still being the main concern, not only to achieve the required soil engineering properties but also by considering the cost and the effect to the environment. The objective of this paper was to review the techniques that had been done for soil stabilization based on experimental studies. Investigation on various materials had been done in order to evaluate their effectiveness as soil stabilizer, which involved the use of sodium hydroxide additive, fly ash geopolymeric binder, various ashes and cementitiousbinders. Thesematerials were discussed in this paper and their effectiveness for stabilizing soft soils were observed from the obtained results,only in term of strength, basedon unconfined compressive strength (UCS) test and California Bearing Ratio (CBR) test that had been conducted. The strength of soft soils was significantly increased with the used of these materials and supposed they had the potential as effective soil stabilizers in field application.

Key words: Soil; Soil stabilizer; Soil stabilization; Unconfined Compressive Strength (UCS); California Bearing Ratio (CBR)

INTRODUCTION

Dealing with soft subgrade or clay soil is one of most major problems (Fauzi *et al*., 2010; Cristelo *et al*., 2013, Senol *et al*., 2006). This situation probably might occur in roadways or highway construction (Fauzi *et al*., 2010, Senol *et al*., 2006) or in geotechnical engineering (Cristelo *et al*., 2013). Since there is reduction in sites for construction development, it is crucial to find ways for soil improvement techniques to respond to the demands (Cristelo *et al*., 2013).

A clay soil in civil engineering means soil that composed of clay minerals and other mineral components, has plasticity and also cohesive. Clays are fine-grained soils but it cannot be simply said that all of fine-grainedsoils are clays. Chemically, clays are combination of hydrous aluminosilicatesand other metallic ions. Flakes or tiny plates form is how the individual crystals look like and numerous crystal sheets consist in these flakes and they have repeating atomic structure. The tetrahedral or silica and octahedral or alumina are the only two fundamental sheets available. Different clay minerals are based on the sheets are stacked, the different bonding they have as well as different metallic ions consist in the crystal lattice. Tetrahedral sheet is a combination of silica tetrahedral units which have four oxygen atomsbasically at the corners and they are surrounding a single silicon atom. Since the oxygen atoms located at the base of each tetrahedron so they are combined to form a structure of sheet. Octahedral is a combination of octahedral units which have six oxygen or hydroxyls surrounding aluminium, magnesium, iron or any other atom. Octahedrons also combine to form a structure of sheet where the rows of oxygen or hydroxyl are in two planes in the sheet. The presence of water is strongly influenced the clay soils. Absorbed water is the layers of water surrounding each crystal of the clay. The absorption of water happened because of three reasons. The first one is because the water has two separate of charges which are positive and negative. So this will caused the molecule of water to be electrostatically attracted to the clay crystal. Second, due to the hydrogen bonding or it can be said the water is actually attracted to the oxygens or hydroxyls on the surface of clay. The last reason, the negative charges of clay surface are attracting thecationswhich present in the water (Holtz and Kovacs, 1981). The water has strong attraction to the clay surface and weakened with distance from the surface. It seems that the water molecules at the surface of clay are very tightly held and strongly oriented (Mitchell, 1976).

To stabilize soft subgrades, the most common or usual approach was by removing the soft soil first. Materials that were stronger, such as crushed rock then will be used to replace it. The cost involved for replacing the materialswas quite high, thus it leads to various researches to find another methods in orderto encounter this problem (Fauzi *et al*., 2010, Senol *et al*., 2006). In order to create an improved soil material which has the desired engineering properties, it is essential for the soil to gone through alteration for one or more properties. Either by doing the alteration by mechanical or chemical, this process is called as soil stabilization (ASTM,

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1992). The purpose of soil stabilization not only limited to enhance the load-bearing of the soil capacity (ASTM., 1992; Bergado *et al*., 1996; Prabakar *et al*., 2004) but also improve the shear strength, filter, drainage system (Prabakar *et al*., 2004), permeability, enhance soil resistance to the weathering process and traffic usage (ASTM, 1992) to meet specific engineering projects requirement (Kolias *et al*., 2005).

Soil stabilization through mechanical and physical techniquescan be done by decreasing the void rate through compacting (ASTM, 1992; Olaniyan *et al*., 2011), the used of fibrous and geomaterials non-biodegradable reinforcement (Olaniyan *et al*., 2011) or altering the grain size physically which also involves the particle size composition adjustment of the soil (ASTM, 1992).Through chemical technique, stabilization can be done by using chemical (Fauzi *et al*., 2010; Graves *et al*., 1988)and emulsions since they work as compaction aids, binders, water repellants and as well as modifying the soil behaviour (Graves *et al*., 1988). Reaction between chemical additives and particles of soil can bind the soil grains through strong network, thus producedsoil with better quality compare to mechanical and physical techniques,since higher strength, durability and quality of soil can be achieved (ASTM, 1992).

The required amount of stabilizing (Olaniyan *et al*., 2011; Ninov *et al*., 2007), type of additives (Ninov *et al*., 2007) and conditions encountered on the project must be determined before choosing the method of soil stabilization (Olaniyan *et al*., 2011). Correct materials and procedures can be selected if an accurate soil description and classification had been done (Olaniyan *et al*., 2011; Ninov *et al*., 2007).

Material Used For Soil Stabilization:

Sodium hydroxide additive:

Sodium hydroxide is highly reactive and it is white, odourless and non-volatile solution. It can generate enough heat to ignite combustible materials nearby and also reacts violently with water and various encountered materials. The main advantage of sodium hydroxide is it can be a great compaction aids by giving higher density for the same compactive effort when react with water (Olaniyan *et al*., 2011).

Fly Ash Geopolymeric Binder:

Geopolymerisation or alkaline activation of aluminate materials is alternative to cement (Hardjito and Rangan, 2005), due to the reduction of CO2 emissions from the activation of ashes and/or slags with the absence of high temperature in calcination step compared to cement production (Cristelo *et al*., 2013). The reduction is as high as 80% based on the activating solution; dissolved solids of Na2O and SiO2 content (Duxson *et al*., 2007). In strength development of alkaline activated systems, sodium hydroxide concentration plays a very important role (Cristelo *et al*., 2012). Sodium hydroxide concentration significantly influenced the strength development (Criestelo *et al*., 2012; Cristelo *et al*., 2013). In geotechnical applications, alkaline activation (geopolymeric binder) of fly ash was tested for soil improvement since waste material was obtained as binder in most of other geopolymer applications (Cristelo *et al*., 2012). Alkaline-activated materials showed better performance since durability and stability can be increased, improvement from mechanical aspect compared to cement and also improved bond between the soil particles and binder (Torgal *et al*., 2012; Villa *et al*., 2010). Alkaline activation generally was a reaction concerning alumina-silicate materials and alkali or earth substances' alkali. At a molecular level to natural rocks, materials formed from reactions between silica, alumina and alkali cations were very alike in term of stiffness, durability and strength (Cristelo *et al*., 2012).

Ashes:

Fly ash and bottom ash are part of combustion of non-combustible residue or combustion of sub-bituminous coal which had been generated in such a huge quantity in electric plants and they are by-product of burning coal (Fauzi *et al*., 2010; Prabakar *et al*., 2004; Ferguson, 1993; Misra, 1988) that can be used without activators for soil stabilization (Ferguson, 1993; Misra, 1988). Fly ash is actually the portion of ash which escapes from the chimney or stack, while on the wall of the furnace is clinkers which formed from bottom ashand will fall to the bottom in a long run (Fauzi *et al*., 2010).Fly ash can be classified to two classes based on the present of calcium content. Class C fly ash usually has calcium percentage above 20% and it was resulted from sub-bituminous coal while class F fly ash, resulted from combustion of bituminous coal usually has calcium percentage which is not higher than 10% (Cristelo *et al*., 2013). Application of other ashes,such as sewage sludge ash to the soft soil was also investigated and it has been combined with other material, cement(Chen and Lin, 2009). This further investigation was due to the several researches which proved that the properties of soil and strength of the soft cohesive subgrade soil can be improved with the application of sewage sludge ash and hydrated lime (Lin *et al*., 2007) and workability and compressive strength of concrete also can be improved by replacing cement with incinerated sewage sludge ash in the making of concrete (Tay and Goh, 1991).

Cementitious Binders:

Mix underperforming soilor soft soils with cementitious binder is one of the major techniques to overcome the created problems and cement and/or lime based are the common binders used.Through chemical reaction, binders such as cement and lime can bond the soil particles together (Cristelo *et al*., 2012; Cristelo *et al*., 2013) but not through physical reactions (Cristelo *et al*., 2013).For civil engineering purposes, lime or cement had been used for improving the handling of soils as well as the mechanical properties (Sherwood, 1993). Cement application in soil however becomes an issue related to environment and durability (Cristelo *et al*., 2013) since it releases high levels of CO_2 during production (Garcia *et al*., 2009) and chemical vulnerability due to sulphates attack in ground or chemical wastes when use in soil improvement or structural foundations (Tomlinson, 2001).The major reaction between lime and soil was to bind together the soil particles through a tough and water insoluble gel (Diamond and Kinter, 1965). For short-term pozzolanic process, the exchanged of ion between calcium ions from lime and cations that closed to the clay particle surface, can transformed soil to a strong flocculated structure from weak dispersed structure. Meanwhile for long-term, pH of water increased due to the increased of hydroxyl ions from lime, which then leads to the dissolved of silicate and aluminium sheets of clay. The clay particles were then binded together silica and alumina, and combined with calcium to form calcium silicate hydrates or calcium aluminate hydrates (Rafalko *et al*., 2008). During the hydration of Portland cements the similar reaction occurred (Way and Shayan, 1989) since pozzolanic component was already integrated in the cement and the reaction only needed water to increase strength (Janz and Johansson, 2002). Gypsum in a form of finely divided powder was reported can be a stabilizing material, not only because of its relatively cost, but it reasonable solubility in water, (Bell and Maud, 1994)but there was not much research conducted by using it as a stabilizer for soft soils (Yilmaz and Civelekoglu, 2009). The performance of gypsum as an additive for soil treatment was studied in term of strength (Yilmaz and Civelekoglu, 2009) due to the positive result obtained from other investigation.Mixture of phosphatic soil and gypsum was reported had an increasement at curing period of 360 days (FIPR, 1988). Cement kiln dust is also an effective stabilizer for certain types of soil since it has cementitious properties (Miller and Azad, 2000). Portland cement is manufactured by mixing the correct portions of lime, silica, alumina and iron. The mixture was then passed through the upper end of a kiln at a controlled rate of the kiln slope and speed. Burning fuel with temperature of 1400-1650˚C at the lower end of a kiln changed the mixture to cement clinker. So, this was the operation where cement kiln dust which also material in the form of dust was collected. The raw materials used and how the cement kiln dust was collected from plant to plant might caused varying physical and chemical properties. The cement kiln dust typically has consistent composition if it was collected from the same kiln which produced the same cement type (Baghdadi *et al*., 1995). Ladle furnace slag is useful in application of improving the soil and usually known as basic slag, reducing slag, white slag and secondary refining slag (Manso *et al*., 2013). Since ladle furnace slag has majority presence of calcium and magnesium oxides, silicates and aluminates (Manso *et al*., 2013), it can be considered as a dusty material which has limited hydraulic reactivity (Papayianni and Anastasiou, 2006). Ladle furnace slag has common chemical features (Shi, 2002) in terms of the presence of dicalcium silicate, calcium aluminates, free lime and free magnesium oxide (Manso *et al*., 2013), and it was useful in improving soils by considering the application of these substances (Manso *et al*., 2005). Its volumetric instability has been concerned (Wang *et al*., 2010) due to the weathering and exposure to air and water, but the use of it in low proportion (less than 10%) in soil mixtures was irrelevant for this expansiveness (Manso *et al*., 2013).

Soil Stabilization Process by Using Different Material:

Sodium Hydroxide Additive:

Sodium hydroxide pellets are added to water to obtain sodium hydroxide solution and varied percentages ranging from 7% to 16% were used to the soil sample while keeping other constituents; 100% filler (sand), 18% water and 100% clay to see the effect of varying sodium hydroxide content. To see the effect of varying filler percentages ranging from 50% to 200%, 13% sodium hydroxide, 18% water and 100% clay soil were kept constant. After obtaining NaOH solution by adding NaOH pellets to water, the solution was added to the clay-sand mixture. Those specimens then put in an oven at 80˚C for 24 hours. After that, they were all subjected to three conditions; some were put in an oven at 40˚C for 2 weeks, some were put in demineralised water for 2 weeks and some were subjected to cycles of wetting and drying (Olaniyan *et al*., 2011).

Fly Ash Geopolymeric Binder:

A combination of sodium silicate and sodium hydroxide were used as the alkaline activator solution. The flake form sodium hydroxide was dissolved in water to obtain different concentration before being mixed with sodium silicate which in solution forms. A ratio of sodium silicate to sodium hydroxide used was 2:1 by mass (Cristelo *et al*., 2012; Cristelo *et al*., 2013). The value of 2 was concluded by Villa *et al*. (2010) can enhance the strength, where higher ratios resulted in higher level of strength. In research done by Cristelo *et al.* (2012) the soil was oven dried and sieved down before being mixed with low calcium content (class F) fly ash and lastly the alkaline activator was added and mixed. The sample was stored in an oven at 60˚C for 12 hours before being removed from the moulds, and put into the sealed bag and stored again in the oven for 2 hours without changing the temperature. Winnefeld *et al*. (2010) reported that curing temperature at 60˚C was chosen because curing at temperature higher than 80˚C might damage the properties. Curing periods were considered by Cristelo *et al*. (2012) at 1, 3 and 7 days. To see the effect of NaOH concentration; 7.5, 10, 12.5 and 15 molal were used.Same concentrations of sodium-based activator; 10,12.5 and 15 molal were investigated by Cristelo *et al*. (2013) with different fly ash percentages; 20%, 30% and 40%. The samples were tested at different curing periods of 7, 28, 90 365 days. Before the activator was added, soil and fly ash were mixed homogenously. After 3 min of mixing, the mixture was cast on the moulds by tapping the moulds then they were left in a sealed container.The samples were removed after 48 hours later and were wrapped in cling film. The samples then were exposed at ambient temperature of 19-23˚C and relative humidity of 40-50% before tested for unconfined compressive strength.

Ashes:

To determine engineering behavioural aspect, Prabakar *et al*. (2004) investigated the used of fly ash ranging from 9% to 46% and added to three different types of soil. Edit *et al*. (2006) studied the used of four fly ashes where two of them were Class C fly ashes and another two were 'off-specification' since they were not meet with Class C or Class F criteria. In order to simulate the natural wet condition observed in the field, samples were prepared approximately wetter 7% than the optimum water content and as standardized condition, specimens were prepared near the optimum water content (Edil *et al*., 2006; Senol *et al*., 2006). Dry basic weight of fly ash and bottom ash contents at 4%, 8% and 12% were prepared separately by Fauzi *et al*. (2010), for stabilizing soil specimens by using different water contents. Kolias *et al*. (2005) used 5%, 10% and 20% amount of fly ash. Different percentages were used by Senol *et al*. (2006), ranging from 10% to 20% of fly ash on dry weight basis. In order to simulate the delay that usually occurred in field construction, the samples then compacted 2 hours later after being mixed with fly ash and water to determine the impact of compaction (Edil *et al*., 2006; Senol *et al*., 2006). Laboratory mixer was used in Kolias *et al*. (2005) investigation to carry out the mixing for at least 2 minutes and then the mix was being put into plastic bags, where the mixing was continued by 5 minutes of shaking and overturning the bag. Edil *et al*. (2005) left specimens in the mold and sealed with plastic wrap right after the compaction. They will be cured at 25˚C before conducted CBR tests to simulate the subgrade preparation for providing working platform and construction activities in practice and in relatively short period. Senol *et al*. (2006) placed each sample in a polyethylene bag immediately to prevent any dehydration and cured in room temperature. The samples will be cured for 7 days with 100% relative humidity before testing were performed (Edil *et al*., 2006; Senol *et al*., 2006). Different with investigation by Kolias *et al*. (2005) were specimens were sealed with thin plastic film after 1 minute completion of compaction and placed in curing room for 20 to 24 hours at 20±1˚C with relative humidity of 96±2%, after the air was squeezed out by hand. The mixture then being remixed again by hand shaking, overturning and squeezing before used. This applied method contained no significant number of lumps which larger than 5 mm. Test were then performed at 7, 28 and 90 days. Chen and Lin (2009) replaced the used of fly ash with sewage sludge ash. Sewage sludge samples were incinerated at 800˚C in an electric furnace. Incinerated sludge sewage ash then not being mixed with soil yet, but mixed with cement in a fixed ratio of 4:1. Admixtures with proportions ranging from of 0% to 16% by weight were then being mixed with cohesive soil. The optimum moisture content was used and the samples were cured for 3 hours and also at 3, 7, 14, 28, 56 and 90 days.

Cementitious Binder:

For cement-based mixtures, Cristelo *et al*. (2013) used percentage of cement at 20%, 30% and 40% of the total dry weight. For cement mixtures, the values of 28 days curing obtained by conducting laboratory tests, while the result for 90 and 365 days estimated by using expression from Eurocode 2. Manso *et al*. (2013) investigated the mixed of clays of smectite and illite groups with 2% of lime. Bell (1996), mixed three of the major constituents; kaolinite, montmorillonite and fine-grained quartz with various amount of lime ranging from 2% to 10% and then samples being compacted at maximum dry density and at optimum moisture content. The samples then allowed to cure for one year at 20^{o}C and were sealed in polythene containers. Clay was mixed with 8% of slaked lime in Ninov *et al*. (2007) research and this amount was chosen due to the practical consideration since pH test had indicated that 5% of Ca(OH)2 was the optimal lime additive. Boschuk (1991) quoted that addition of 15% lime leads to decrease in strength characteristics. In Ninov *et al*. (2007) research, optimum moisture content was used to prepare the sample specimens by compaction. To restrict the admittance of CO2, specimens were kept in a closed thermostatic vessel at temperature 298 ± 1 K, where the vessel were saturated with water vapours. In Kolias *et al*. (2005) investigation, combination of soil and lime also were tested where designed quantity of hydrated lime used was equal to the quantity of free lime contained in the fly ash. Miller and Azad (2000) mixed three different soil samples with varying plasticity index with different percentage of cement kiln dust. Samples were prepared for each curing period and they were wrapped in cellophane and stored in humidity chambers. After the prescribed curing day samples were tested. For compression testing the samples were curing at days 7, 14 and 28. Peethamparan *et al*. (2009) also used unreacted (dry) cement kiln dust powder and dry Na-montmorillonite clay where the clay was mixed with 25% of cement kiln dust by the weight of clay and the samples were compacted approximately at the optimum moisture content of 38%. The two dry components, cement kiln dust and clay were mixed homogenously for 15 min before distilled water was added. The samples were then extracted immediately after compaction and wrapped in the plastic bags before placed in sealed plastic boxes. They were also kept in a room at a constant temperature of 23˚C at 100% relative humidity and curing periods were at 1, 7, 28 and 90 days. Yilmaz and Civelekoglu (2009) investigated different amount of gypsum; ranging from 2.5%, to 10% by mass, mixed with clay with contains dominantly Na-smectite and cured for 7 days after compacted by using the optimum moisture content. During the curing period, samples were kept in polyethylene bags in glass dessicator before taken out to perform testing. Manso *et al*. (2013) mixed two different types of soils; clay which mainly consisted of illite and the other one was clay of smectite group with 5% of ladle furnace slag. The samples were monitored at 0, 3, 7, 28 and 90 days.

Strength of Soil After Stabilization by Using Different Material:

Sodium Hydroxide Additive:

Olaniyan *et al*. (2011) found that the increase in clay to sand ratio, or lower percentage of filler used, results in the enhancement of kaolin activity. Thus, this had speed up the process of mineral polymerization. The strength increases because more amounts of hard geopolymeric products produced by higher kaolin activity. The compressive strength was highest, at the highest clay to sand ratio. Compare to all specimens, dried specimens had the highest compressive strength and soaked specimens were the lowest. Through alkaline attack, sodium hydroxide can change the clay mineral lattice and it creates strong relationship between compressive strength and sodium hydroxide content. Sodium silicate and sodium aluminates are the products of the degradation, which then continue to precipitate insoluble aluminium oxide hydrates in soil. Higher strength can be achieved with higher NaOH content.

Fly Ash Geopolymeric Binder:

Cristelo *et al*. (2012) found that, increased in sodium hydroxide resulted increased of strength based on the unconfined compressive strength value after 7 days curing. There was no significant different of unconfined compressive strength value for 12.5 molal and 15 molal. So, 12.5 molalwas determined as the optimum concentration, in designing field applications by considering not only unconfined compressive strength value but the cost and workability.Since 15 molal had very poor workability, the moulding process took about 4 to 5 minutes to be completed. High speed of dissolution and lesser time for gel to grow into well-crystalline structure can be achieved with more availability of alkali in the mixture (Jimenez and Palomo, 2003). Cristelo *et al*. (2012) found that the performance of 15 molal cannot be sustained for longer period due to the decrease of raw silica when faster formation of polymeric matrix. Based on the different activator: solid ratio (soil and ash), there was an optimum activator: solid value which results in the higher compressive strength, at around 0.375. This can be explained by the theory of dry unit weight – liquid content relationship. Water occupied voids that could be filled with solid particles when water content value higher than the optimum result, while compaction process become more difficult when water content lower than the optimum result.Temuujin *et al*. (2010) quoted that when sand and other aggregates were added to the composition of sodium silicate solution and NaOh and/or KOH solution, resulted to a not well-defined interface between the binder and siliceous materials. The same result obtained when the fly ash-based geopolymer mortars were mixed with varying sand aggregates content.Cristelo *et al*. (2013) also investigated the used of different concentration of sodium-based alkaline activators and different percentage of fly ash. For 20% and 30% fly ash mixtures, 15 molal produced the highest result of unconfined compressive strength, except for the 40% fly ash mixture where 12.5 molal concentration produced the highest value. Lower strength values was obtained due the polymeric gel which available at medium to long term in 15 molal mixture and also due to original reactive silica which had been prevented from being more dissolved. The mixture of 15 molal had higher short-term strength when mix with 20% and 30% of fly ash due to the quick dissolved of vitreous phase from fly ash, so the gel had no enough time to grow into a well crystallised structure.

Ashes:

The amount of fly ash influenced the increase in CBR values (Fauzi *et al*., 2010; Prabakar *et al*., 2004), soil type (Edil *et al*., 2006) and so do the bottom ash and water content in the mixture (Fauzi *et al*., 2010). But it clearly indicates that the higher content of fly ash the higher CBR values of the soil (Fauzi *et al*., 2010; Edil *et al*., 2006). Research done by Fauzi *et al*. (2010) found that either fly ash or bottom ash; both contribute to higher CBR value regardless the differences in water content. For Class F and 'off-specification' fly ashes, increase in soil water content relative to optimum moisture content results in decreasing of CBR value. Both do have the similarity in terms of sensitivity water content (Edil *et al*., 2006). Prabakar *et al*. (2004) quoted that the addition of fly ash for the improvement of soil strength is the function of soil fly ash interlocking phenomena. Edil *et al*. (2006) found that for soils which prepared 7% wetter than optimum water content, CBR value range from 0 to 5 and indicated that the soils are very poor subgrades in their in situ condition, if most of them less than 2. But when mixed with fly ash CBR value typically range between 10 to 20. When fly ash was added to wetter or more plastic fine-grained soil, the CBR increased by a great factor. Investigation by Senol *et al*. (2006) found that the amount of fly ash and water content in the mixtures had great influenced towards increasing the value of strength. Low plasticity clay had higher unconfined compression strength value compare to high plasticity clay but for CBR value it was opposite where high plasticity clay recorded higher value. It has been clearly proved that for both tests, decrease in strength was due to the higher water content, for mixtures that 7% wetter than the optimum water content. Kolias *et al*. (2005) quoted that the higher amount of fly ash used increase the unconfined compressive strength of the soil. But the use of large quantity of fly ash would be the problem and stabilised with small percentages of fly ash and cement could be considered. By using sewage sludge ash, Chen and Lin (2009) found that all proportions that had been used to the specimens showed such a great increased in UCS especially when the curing time reaches 90 days. The 2% and 4% admixtures added showed the best increments compare to the others. The CBR values also increased where the results clearly indicate that the soil conditions were getting better from poor to excellent. When the proportion of the admixture was added more the soil condition improved to be even better than excellent. So the soil has higher bearing capacity when added to the untreated soil thus can be an effective stabilizer for soft subgrade soil.

Cementitious Binder:

Cristelo *et al*. (2013) found that the cement mixture of 0.75 was the best water cement ratio and higher ratio than that resulted loss of strength. Kasama *et al*. (2007) quoted that several research also proved that in a wide range of cement content, 30% gave the higher value of unconfined compressive strength. This also can proved from the result obtained by Cristelo *et al*. (2013) where at the curing days of 365, the cement content of 30% had the highest unconfined compressive strength value. Ninov *et al*. (2007) found that the addition of 8% lime had an increase in strength during the first 6 months and after prolonged storage it can leads to a higher compressive strength. The reaction of lime with illite as the basic component of the clay were completed for about 3 to 4 months. Rafalko *et al*. (2008) quoted that soil type and mineralogy will influence the optimal dosage rate of lime for maximum strength gain unlike cement where the strength of the soil keep increasing when the dosage rate increase. When the dosage of lime is too high, the maximum strength might not be obtained due to the decrease of dry density of soil-lime mixture. Investigation done by Miller and Azad (2000) found that the unconfined compressive strength also can be improved by the addition of cement kiln dust and it was more significant with the soils with lower plasticity index. During the first 14 days the most significant strength occurred and the increased of cement kiln dust content resulted increased in unconfined compressive strength value. Peethamparan *et al*. (2009) also found that the unconfined compressive strength of CKD treated clay was progressively increased from day 1 to 90 due to the induction of cement kiln dust which extensively change the physico-chemical properties of Na-montmorillonite clay. Bell (1996) studied the addition of lime to montmorillonite clay and found that there was a rapid initial increased in unconfined compressive strength even with small additions of lime. The same goes to kaolinite and quartz where lime gave rise in outstanding increases. The optimum lime strength for montmorillonite was about 4%. For kaolinite the optimum lime strength was varied between 4% and 6% while quartz between 4% and 8%. It was clearly shown that for montmorillonite low amount of lime can attained maximum strength compare to higher content. Strength was not linearly increase with lime content and strength was reduce with excessive addition of lime. Curing was one of the major important variables which affect the strength of lime stabilized clay soil in terms of function of time, temperature and also relative humidity. Bell (1996) also concluded that during the first 7 days of curing, the strength increase rapidly then increases more slowly after that at more or less constant rate. Even though soil-lime stabilization has been proved can increase the strength of the soil, the strength values obtained from combination of soil and lime were considerably lower than the values obtained from combination of soil and fly ash due to the hydraulic and pozzolanic reactions (Kolias *et al*., 2005). The rate of strength gain by soil was investigated by Yilmaz and Civelekoglu (2009) by using gypsum. It was slow but it keep increasing and the maximum strength was obtained at 7 days of curing. Different amount of gypsum was used but 5% of gypsum content showed an effective improvement compare to the others. Manso *et al*. (2013) found significant improvement when clays were mixed with ladle furnace slag in terms of mechanical behaviour and compressive strength. The compressive strength for clay which mainly consisted of illite and ladle furnace slag was better, since it kept increasing as from days three onwards compare to the clay and lime mixture. For smectite group of clay, the compressive strength was maintained and only increases at an age of 28 days but the result was much similar with clay and lime mixture except at days 90 where the result was improved.

Conclusion:

From this review paper, it can be concluded that the effectiveness of materials discussed above was already proven can stabilized the soft soils or improved the soil strength. But, further investigation has to be done in order to evaluate their effectiveness in field application rather than focusing in term of experimental studies. Other investigation also needs to be done so that other materials that would be effective as soil stabilizer could be found.

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