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STRENGTH AND DURABILITY EFFECT ON STABILIZED SUBGRADE SOIL

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Abstract – This paper presents the development of strength and durability effect of stabilized soil. The clayey soil collected from Kota Samarahan, Sarawak was admixed with cement, fly ash and rubberchip as an additive for stabilization purposes. The optimum mixture determined was then used as a recommendation for the design guidelines of sub-grade based on JKR Standard Specification for Road Works. The stabilized clay specimens were prepared with 5% cement and various fly ash and rubber chips contents, of 5%, 10% and 15%, respectively. The specimens were then cured for 7 and 28 days before subjected to Unconfined Compressive Strength (UCS) tests and California Bearing Ratio (CBR) tests. As observed, the stabilization improved the strength and stiffness of the soil properties significantly. However, the addition of 15% rubberchip shows a reduction in strength for both 7 and 28 days curing period. From the study, the optimum mixture, which fulfilled the JKR Standard Specification was the mixture of 5% cement and 15% fly ash. However, the mixture of 5% cement and 10% rubberchip is also recommended to be used as an alternative to stabilize the subgrade for low volume road.

Keywords**:** fly ash, rubberchip, subgrade

1.0 INTRODUCTION

In road and highway constructions, not only the pavement or premix quality is given serious scrutiny, but the substructure below the pavement is also equally vital. The stability of the underlying soils needs serious attention so as to ensure that the pavement structures that has been constructed can enhance the durability of the pavements. It is important to provide the optimum performance for the pavements because the pavement structures are significantly impacted by the direct loading of the traffic. Unfortunately, in Sarawak, some locations are frequently not adhered to the project requirements due to the availability of the soft soil and it is clearly inadequate for the traffic loading demands. In order to meet such requirements, the subgrade material requires a treatment to stabilize the soils in the specified area to provide a stable subgrade and also a suitable working platform for the needs of the pavement construction. As the materials used for road construction are getting more expensive, stabilizing the local soil and improved its physical properties through soil treatment is one of the alternatives.

The Portland cement, which is basically a compound of silica, alumina and iron has been widely used in order to stabilize soils especially in the highway construction [1], [2]. There are two basic reactions occur in cement stabilization which is hydration and pozzolanic reactions and it is well documented in the literature [3], [4]. As stated by [3], when cement is combined with water, the hydration reactions will occur and the cement-treated material will gain strength as well as the pozzolanic reactions that contribute to the strength of a specimen. An experimental work done by [5] shows that compressive strength development for 7 days soaked clay soil-cement mixture are 200 psi to 400 psi and for 28 days the results shows that it can reach 250 psi to 600 psi by using 9% to 16% of cement. However, [6] come out with a suggestion of the required cement quantity as 4% to 6% from the dry mass of the soil that can gain the strength of 100 psi (700 kPa) and they also concluded that the amount of 4% cement by dry weight of the soils are adequate for cement stabilization. [2] also stated that a reasonable criterion for soil stabilization is the increase of the strength of the untreated soil compared to the stabilized soil by 50 psi (350 kPa) or greater under the same condition of compaction and cure. The cement used in this study is Ordinary Portland cement produced by Cahaya Mata Sarawak Corporation (CMS).

The utilization of fly ash in stabilizing the clayey soil also has been studied by various researchers [2], [3], [7], [8], [9]. Fly Ash which is the product of the combustion of coal is one of the stabilizers used in subgrade soil stabilization for the construction of roads [7], [8]. It can provide the pozzolanic reactions to strengthen the clayey soils as the lack of silica and alumina in the soft soil will caused a failure. [9] pointed out that when exposed to water, fly ash will be hydrated and it can be used as a drying agent for wet soils and also acts as a weak cementing agent that increases the strength of the treated soil. In this study, the Class F fly ash was used as one of the stabilizing agent to strengthen the soil properties and the addition of 5% cement was used in order to enhance the ability of the fly ash to react with the pozzolanic activities as it contains very little amount of lime.

A study done by [10], shows that the strength improvement cannot be achieved by using rubberchip alone. However, the failure of the axial strain percentage was increased for the specimens with rubberchip as compared to the specimens without rubberchip as an additive. Regarding to [10], the soft soil that was stabilized with 5% mixture of cement together with rubber chips of various quantities of 5%, 10% and 15% from the soils dry weight can increase the cohesion value of the soft soil mixture from 0.06 to 0.70kN/m^2. From the study, it is shown that significant improvement in the undrained shear strength of the soft soil can be obtained from cement- rubberchip admixtures. From the previous study of [11], it has shown that the rubber can be a flexible filler material in the soft soil stabilization where 2% to 4% of rubbershred based on the dry weight of soil were prepared to the specimens. The study by [12] also agreed that the strength of naturally weak and soft soils like clay can be improved by stabilizing the soils with the mixture of cement-rubberchips. They also stated that it is practical to apply the rubberchips as one of the alternative material in order to improve the soft soil strength characteristics. The rubberchip that is used in this study is a product from Zhen Hak Ann Tyres Recycle Sdn Bhd located in Jalan Batu Kawa – Matang, Sarawak. The rubberchip is between 1 mm to 4 mm of particle sizes and it is taken from the raw material without sieving to the addition of the mix design.

This paper presents an investigation to determine the strength development and durability effect of stabilized subgrade. This was conducted by performing Unconfined Compressive Strength (UCS) Tests, California Bearing Ratio (CBR) Tests, and Compaction by Standard Proctor Tests.

2.0 SOFT SOIL CHARACTERISTICS

A total 7 design mixtures were prepared in order to investigate the durability and strength development for the soft soil stabilization and 1 set of specimens is prepared for the untreated soil for comparison purposes. For each design mixture, there are 3 specimens prepared and the total specimens prepared were 96 specimens for UCS Tests and another 96 specimens for CBR Tests. The tests were conducted in two conditions namely, soaked and unsoaked and it is conducted in accordance to the British Standard 1377. The design mixture is indicated as follows:

1. 5% cement (5C)
2. 5% cement with 5% fly ash (5C_5FA)
3. 5% cement with 10% fly ash (5C_10FA)
4. 5% cement with 15% fly ash (5C_15FA)
5. 5% cement with 5% rubberchip (5C_5RC)
6. 5% cement with 10% rubberchip (5C_10RC)
7. 5% cement with 15% rubberchip (5C_15RC)

The tests is taken by two (2) phases which is to determine the soft soil characteristics and then to measure the engineering properties of the design mixtures. The soil characteristic that are being measured are the moisture content, specific gravity, Atterberg Limit and grain size distribution by conducting sieve analysis and hydrometer analysis tests. In Atterberg Limit tests, Liquid Limit (LL) and Plastic Limit (PL) were obtained before Plasticity Index (PI) was determined. The durability effect of the stabilized material is important for subgrade soil as the foundation of engineering structure [13]. In an effort to prevent subgrade failure, many studies with different protocols have been made in this study to evaluate the strength properties of the stabilized materials. Various laboratory tests of particular interest were conducted in this study namely Unconfined Compressive Strength Tests (UCS), California Bearing Ratio Tests (CBR) and Compaction Tests by Standard Proctor. Standard Proctor tests were conducted to obtain the optimum moisture content and dry unit weight of the clay sample and the mix designs. Unconfined compressive strength for clay with the various design mixes was obtained based on cured sample for 7 and 28 days. The tests were conducted in two conditions, which are soaked and unsoaked. California Bearing Ratio (CBR) tests were also being conducted to obtain the geotechnical properties of the mix design with soaked and unsoaked conditions for 7 and 28 days curing period.

3.0 SOIL PROPERTIES

Table 1 tabulated the general properties of the soil, as can be seen the moisture content is about 30.34%. The Atterberg limit value is 26.70% for LL whereas the plasticity index was 5.11%, respectively. Based on the plasticity chart the soil can be classified as low plasticity clayey silt, CL-ML.

Table 1: Geotechnical Properties of the Kota Samarahan Soft Clay

General Geotechnical Properties		
Water content, w_o	(%)	30.34
Liquid limit, LL	(%)	26.70
Plastic limit , PL	(%)	21.59
Plasticity Index, PI	(%)	5.11
Liquidity Index, LI	(%)	1.71
Shrinkage limit, SL	(%)	2.87
Specific gravity, G_s		2.35
Grain size distribution:	(%)	
Clay (<0.002 mm)		24.00
Silt (<0.075 mm)		34.00
Sand (>0.075 mm)		37.00
Gravel		5.00

4.0 COMPACTION EFFECT OF STABILIZED KOTA SAMARAHAN SOFT CLAY

Figure 1 illustrates the moisture-density relationship of the untreated and treated stabilized soil mixture, respectively. In general, the addition of cement, fly ash, and rubberchip for every soil mixture shows an increasing value in optimum moisture content and has different trends in their values by the increased fly ash and rubberchip amount along with 5% cement addition. However, the changes was considered small in the optimum moisture content and also in the maximum value of the dry unit weight due to the hydration process (from the addition of cement) that are not occurred in a short time period.

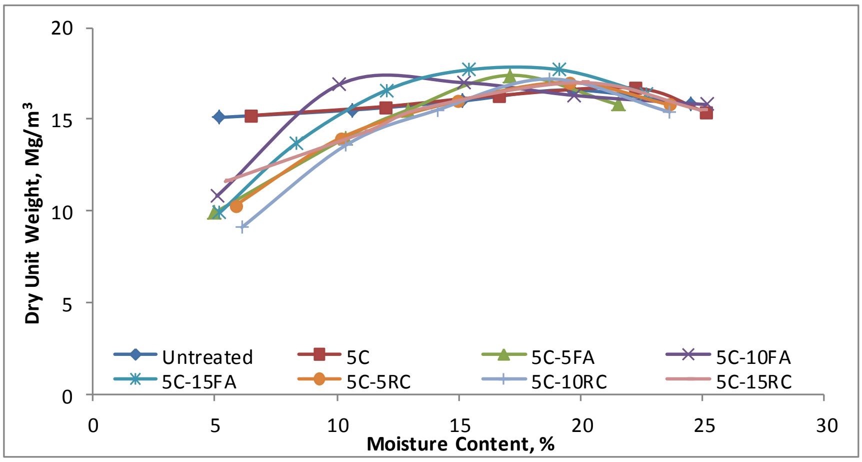


Figure 1: Relationship of dry unit weight versus optimum moisture content

5.0 STRENGTH DEVELOPMENT OF STABILIZED KOTA SAMARAHAN SOFT CLAY

The unconfined compressive strength (UCS) tests were conducted according to BS1377-7:1990 [14] in two conditions namely soaked and unsoaked. The soaked conditions represent the subgrade condition during heavy rainfall or drained condition while unsoaked represent normal rainfall or undrained condition. The stabilization of soil by using cement, fly ash and rubberchip generally increased the strength of the soil. However, the strength developments are dependent on the amount of stabilizers used. In order to get the best average value, three samples for each mixture were prepared for the purposes of the tests.

Figures 2 and 3 present the results obtained for 7- and 28-day curing time for all soil mixture samples. The highest strength was obtained from the mixture of the soil with 5% cement and 15% fly ash with the value of 941.69kPa which is 69.5% increase from the strength for 7-day curing period. The value obtained is greater than 0.8MPa required for the stabilized subgrade by [15]. The unconfined compressive strength values increased with continuous increasing of the fly ash content (from 5% to 15% fly ash). The highest strength gained for the soil mixture with cement and rubberchip is the mixture of 5% cement and 10% rubberchip in unsoaked condition where the strength gain about 50.7% value from 380.5kPa in 7-day curing period to 771.77kPa on 28th day. However, the rest of the mixture of rubberchip does not gain too much strength at the later age. Moreover, the strength value decreased for the rubberchip mixture of 15% rubberchip for both soaked and unsoaked conditions. From the findings, it can be concluded that the treated soil with rubberchip at early days curing period is characterized by a high strength but small strain at failure. Meanwhile, soil treated with fly ash shows larger strain before failure as it is stiffer than the rubberchip mixtures.

In addition, for the 7-day curing period, the untreated soil specimens had reach the strengths of 171.72kPa at optimum moisture content compaction while for 28th day of curing, the average value of the strength is 174.77kPa. According to [16], in the pavement applications, the strengths of the untreated soils that were compacted should be interpreted by general relationship between the soil consistency and its strength. Unfortunately, it is noted that untreated specimens were disintegrated after being submerged in water.

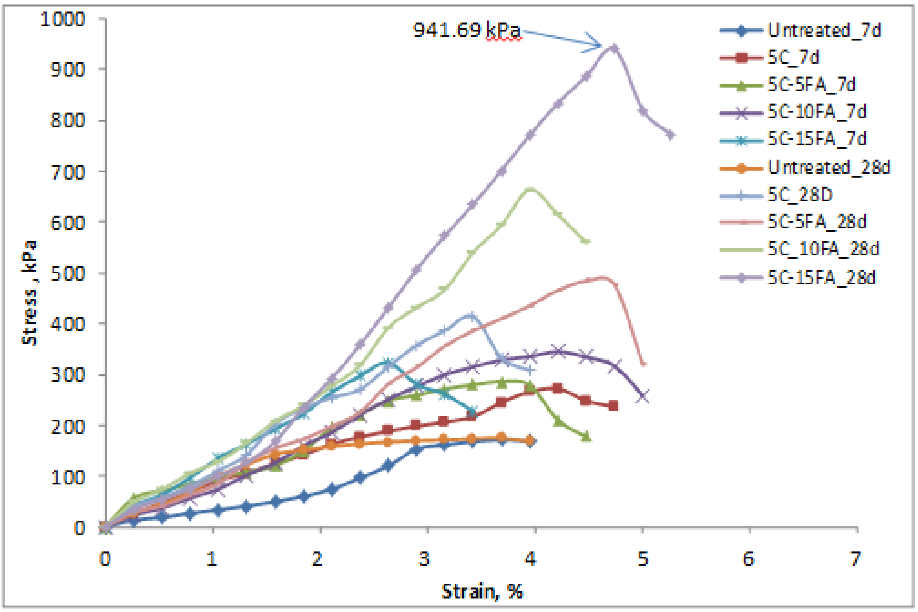


Figure 2: Unconfined compressive stress tests for fly ash

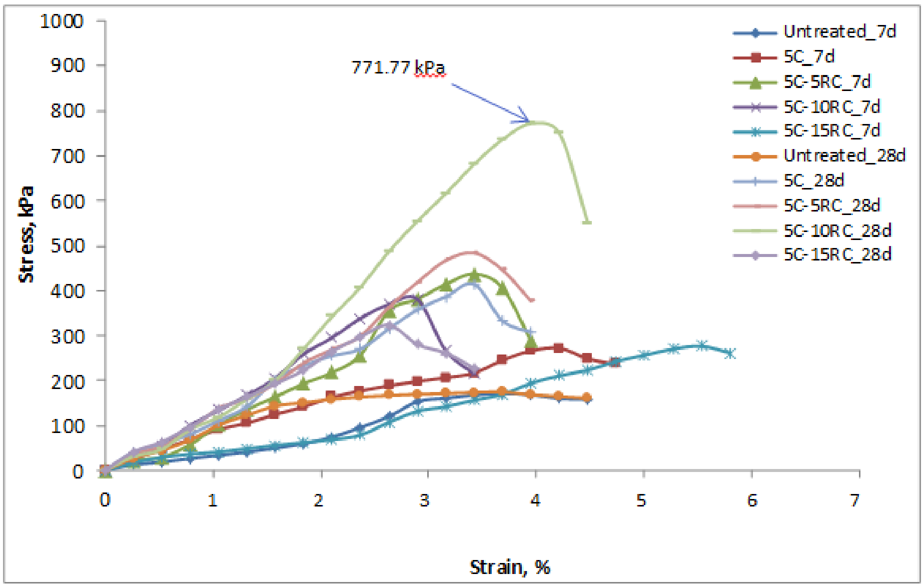


Figure 3: Unconfined compressive stress tests for rubberchip

6.0 DURABILITY EFFECT OF STABILIZED KOTA SAMARAHAN SOFT CLAY

The results of conducted CBR tests for soil samples with different percentages of stabilizers content are shown in Table 2. Based on the table, the value of the mixture to achieve 80% CBR value is obtained from the mixture of the soil with 5% cement and 15% fly ash.

It was also found that the percentage of CBR increases with strength due to the addition of stabilizers. The increasing trend of the CBR values by increasing the fly ash and rubberchip content is observed for all mixtures except for the mixture of 5% cement with 15% rubberchip. Surprisingly, the mixture shows the lowest CBR value for both soaked and unsoaked conditions as compared to other percentage of stabilizers.

Table 2: CBR value for unsoaked and soaked condition for Kota Samarahan soft clay

Admixture mixing			**Curing Time**	**Unsoaked**		**Soaked**	
Cement (%)	**FA (%)**	**RC (%)**	**days**	**Penetration of 2.5mm,%**	**Penetration of 5 mm,%**	**Penetration of 2.5mm,%**	**Penetration of 5mm,%**
Untreated soil			7	6.30	6.00	4.23	4.18
			28	19.80	6.26	29.28	13.37
5	0	0	7	16.59	48.52	29.90	20.65
			28	35.89	20.31	13.06	6.94
5	5	0	7	46.55	41.87	26.52	17.10
			28	54.00	51.35	36.22	35.77
5	10	0	7	30.92	30.81	14.56	9.65
			28	67.71	54.84	20.99	17.83
5	15	0	7	81.13	65.00	32.39	28.78
			28	82.60	78.77	72.28	71.55
5	0	5	7	28.86	14.90	24.38	16.59
			28	50.56	35.89	29.79	29.23
5	0	10	7	51.12	18.28	16.94	23.19
			28	64.66	61.28	9.82	4.74
5	0	15	7	5.59	13.54	2.37	9.25
			28	6.43	15.69	5.25	15.23

For the purpose of designing a stabilized subgrade according to [17], the mixture of 5% cement + 15% fly ash is sufficient to use for a high volume road while for designing a subgrade of low volume road, the mixture of 5% cement + 10% rubberchip can also be taken into consideration. The value gain is useful to determine the optimum additives content to be used for road construction when dealing with silty clayey subgrade for the local area.

Table 2 also shows the effect of rubberchips of soaked and unsoaked CBR values of the mixtures of clay-cement-rubberchip. Both soaked and unsoaked values of these mixes initially increased up to 64.66% before they decreased when 15% rubberchip was added. The maximum value of CBR for the clay-rubberchip mixture was achieved with the addition of 10% rubberchip. The increasing value in CBR results was due to the characteristics of the rubberchips, which reinforced the mixture. The reinforcing characteristics prevent the cracks formation in the sample and binds together the soil particles which resulted in the increasing values of CBR. However, the increasing content of rubberchip decreases the distance of soil particles and the rubber chips, hence contributed to the increase in the volume but decreased the dry density. Hence, adding too much rubberchips could reduce the effectiveness of the improvement in the strength of the soil mixture, as fibres will adhere to form cluster and cannot be fully contacted with the soil particles [10],[18].

Figure 4: Examples of cracks formation in the mixture of clay-cement

Figure 5: Examples of cracks formation in the mixture of clay-cement-fly ash

Figure 6: Examples of cracks formation in the mixture of clay-cement-rubberchip

7.0 DESIGN GUIDELINES BASED ON JKR STANDARD

According to [17], both stabilized base materials and stabilized subgrade must have a minimum CBR of 80% and Unconfined Compressive Strength (UCS) of at least 0.8 MPa. From the laboratory experiments, the suitable design mixture that complies with this standard is the mixture of soil with 5% cement and 15% fly ash which the value of CBR was 82.6% and the UCS value was 941.69 kPa, respectively. The pavement design can be used as a guideline for a silty clayey soil in the local area of Kota Samarahan. The design mixture used minimum cement contents and optimum moisture contents to achieve the required strength for the traffic volume loading.

Based on the findings, the calculation for the pavement design was calculated using MathCad15 (PTC, 2010) by considering several input parameters such as Initial Daily Traffic Volume, the percentage of subgrade CBR value, etc. Then, the design of appropriate pavement structure was selected based on traffic category by using Manual for the Structural Design of Flexible Pavement produced by JKR. The Manual recommended a single tool that represents a design approach which combines the improved design data and methods of analysis and it present the predesigned pavement structures in the form of catalogue.

Several criteria or parameters have to be considered in order to design an appropriate flexible pavement for the selected area. The input parameters that will be used to design a stabilized subgrade thickness for a pavement are as follows:

1. Initial Daily Traffic Volume (ADT)
2. Percentage of commercial vehicle, Pc
3. Annual growth rate, r
4. Equivalent factor, e
5. Subgrade CBR value (%)
6. Equivalent Standard Axles (ESAL)
7. Reliability, R
8. Serviceability Index
9. Directional lane distribution
10. Lane distribution

In designing an appropriate pavement structure, the first step is to calculate the design traffic by using parameters given by JKR and the Highway Planning Unit. The data is important in order to determine the loads that must be supported over the design life of the pavement. Then, the properties of subgrade are defined by using CBR tests result before determining the subgrade category that represents the subgrade strength. The subgrade category can be chosen by using Table 2 based on the percentage of CBR value. The last step is to select one of the pavement structures that can be selected in the catalogue contained in the Manual for the Structural Design of Flexible Pavement. The selected pavement structure depends on the subgrade category.

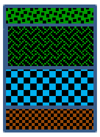
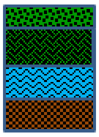
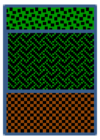
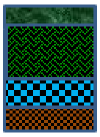
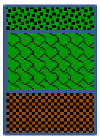
Table 3: Classes of Sub-Grade Strength (based on CBR) used as Input in the Pavement Catalogue (Manual for the Structural Design of Flexible Pavement, 2013)

Subgrade Category	CBR (%)	Elastic Modulus (MPa)	
		Range	Design Input Value
SG 1	5 to 12	50 to 120	60
SG 2	12.1 to 20	80 to 140	120
SG 3	20.1 to 30	100 to 160	140
SG 4	> 30	120 to 180	180

Based on the previous CBR results, Table 4 shows the alternative pavement structure based on the subgrade category for the optimum design mixtures.

Table 4: Alternative pavement structure based on traffic category for optimum design mixtures

No	Design Mixture	Stress (kPa)	Sub-grade Category	CBR (%)	Pavement Structure		
					Option 1 Conventional Flexible: Granular Base	**Option 2 Deep Strength: Stabilized Base**	**Option 3 Stabilized Base with Surface Treatment**
1.	5% Cement + 15% Fly Ash	941.69	SG 4	> 30	**Traffic Category T1** BSC: 50 CAB: 100 GSB: 100	BSC: 50 STB2: 100 GSB: 100	Surface Treatment GSB: 250 OR Surface Treatment STB2: 200
2.	5% Cement + 10% Rubberchip	771.77	SG 4	> 30	**Traffic Category T2** BSC: 100 CAB: 200 GSB: 100	BSC: 100 STB2: 120 GSB: 150	BSC: 50 BB: 80 GSB: 150
3.	5% Cement + 15% Fly Ash	941.69	SG 4	> 30	**Traffic Category T3** BSC: 50 BC: 130 CAB: 200 GSB: 100	BSC: 50 BC: 100 STB1: 100 GSB: 100	BSC: 50 BC/BB: 130 GSB: 100
4.	5% Cement + 10% Rubberchip	771.77	SG 4	> 30	**Traffic Category T4** BSC: 50 BC/BB: 150 CAB: 200 GSB: 100	BSC: 50 BC/BB: 130 STB1: 100 GSB: 100	BSC: 50 BC/BB: 150 GSB: 100

No	Design Mixture	Stress (kPa)	Sub-grade Category	CBR (%)	Pavement Structure		
					Option 1 Conventional Flexible: Granular Base	Option 2 Deep Strength: Stabilized Base	Option 3 Stabilized Base with Surface Treatment
5.	5% Cement + 15% Fly Ash	941.69	SG 4	> 30	Traffic Category T5  BSC: 50 BC/BB: 190 CAB: 200 GSB: 100	 BSC: 50 BC/BB: 140 STB1: 150 GSB: 100	 BSC: 50 BC/BB: 180 GSB: 100
					Option 1 Special Purpose Surface Course	Option 2 Deep Strength High Modulus Base Course	
6.	5% Cement + 10% Rubberchip	771.77	SG 4	> 30	Traffic Category T5 (Polymer Modified Asphalt)  SMA, PA, FC or PMA: 50 BC/BB: 150 or PMA: 120 CAB: 100 GSB: 100	 BSC: 50 BC/BB: 200 GSB: 100	

GSB - Subbase Course: Crushed or natural granular material with maximum 10% fines
CAB - Road base course: Crushed granular material with maximum 10% fines
STB1 - Road base course: Stabilized base with at least 3% Portland cement
STB2 - Road base course: Stabilized base with bituminous emulsion and maximum of 2% Portland cement
BB - Road base course: Course bituminous mix, AC28
BC - Binder course: Course bituminous mix, AC28
BSC - Wearing Course: Asphaltic Concrete - Medium to fine bituminous mix, AC10 or AC14
PMA - Wearing Course: Polymer Modified Asphalt
SMA - Wearing Course: Stone Mastic Asphalt
PA - Wearing Course: Porous Asphalt
FC - Wearing Course: Gap-Graded Asphalt

8.0 CONCLUSIONS

This study has made a comprehensive examination of the effectiveness combination of cement, fly ash, and rubberchip as one of the options in stabilizing the geotechnical properties of soils encountered in Kota Samarahan, Sarawak. The results of the study provide valuable details on the properties, compaction and strength characteristics of the silty clayey soil as well as those mixed with 5% cement and different percentages of fly ash and rubberchip. The results obtained from the California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) tests were thoroughly analyzed. The mixture that presents the best result in stabilizing subgrade and satisfied the requirement with JKR Specification was selected as the design value in the design for pavement. The strength increment was observed for both stabilized soils by the increasing amount of fly ash and rubberchip except for the addition of 15% rubberchip. The similar behaviours were then observed for the cement stabilized soil with fly ash but the addition of the soil-cement mixture with rubberchip above 10% shows a reduction in the strength of the stabilized soil. For durability (water-soaking) tests, both fly ash and rubberchip soil-cement mixtures have lost their strength due to the water soaking procedure. The percentage of reduction for soil-cement mixture with fly ash is 44% while 43% reduction can be seen from the mixture of soil-cement and rubberchip. Although the mixture of cement-fly ash used in this study was performed well with the silty clayey soil, further research on various types and sources of fly ash in treating subgrade soils is needed as the inherent in fly ash composition was basically different depends on the sources of the raw materials. Furthermore, a related research should be conducted in developing an appropriate connections for Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) laboratory values for the long-term performance of in-situ stabilized soils with the durability of the treated specimens.

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