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EFFECT OF CEMENT AND BY-PRODUCT MATERIAL INCLUSION ON PLASTICITY OF DEEP MIXING IMPROVED SOILS

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ABSTRACT

Cement deep soil mixing is one of the most widely used ground improvement techniques to enhance the strength of weak soils for construction purpose. One of the engineering parameter that influences the strength performance of the improved soil is plasticity. This paper investigates the effect of cement and inclusion of waste materials on the plasticity of deep mixing improved soils. Two waste materials namely, Pulverised Fuel Ash (PFA) and Ground Granulated Blast Slag (GGBS) were considered. The investigation was carried out on five different soil samples with natural plasticity of 5%, 10%, 15%, 37% and 45%. In the first phase of improvement, samples were mixed with 5%, 10%, 15% and 20% cement (CEM I) content by weight of dry soil. In the second phase, the cement contents were reduced by 50% and replaced with PFA. In the third phase, cement was further reduced by 33.3% and replaced with equal amounts of PFA and GGBS. All improved samples were cured under 100% relative humidity and subjected to liquid and plastic limit test after 3days. Analysis of results showed that for cement improved soils, increase in cement content beyond 15% by weight of dry soil increases plasticity index of improved soils. The inclusion ofPFA and GGBS to cement during deep soil mixing reduces the plasticity index of the improved soil and may enhance the strength gain over time. PFA and GGBS could be used in deep soil mixing with reduced amount of cement and thus reducing cost, CO_2 emission and the environmental impact of cement deep soil mixing. The results have shown that 15% cement is the optimum amount of cement required for deep mixing improvement of soils with natural plasticity index of 5-45%. The inclusion of GGBS and PFA in the blended soil reduces the amount of cement required for optimum binder content and resulted to 20% Cement/GGBS/PFA optimum binder content in the ratio of 1:1:1. This study has shown that addition of 15% cement content and 20% Cement/GGBS/PFA resulted to improved soils with plasticity index less than 17% making the investigated soils suitable for use as embankments and pavement for light to medium traffic. It could also be added that soil-binder interaction depends on soil type and the extent of improvement in plasticity index depends on plasticity index of the natural soil. A generalised flow chart based approach as a function of plasticity index of the natural soil have been developed for selection of binder for use in construction where increase in strength is envisaged.

Key words: Soils, deep soil mixing, natural plasticity, GGBS

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1. INTRODUCTION

Soil improvement becomes very necessary when the present state of a soil in terms of its engineering properties fails to meet the proposed use of the site. Deep soil mixing techniques have been designed to address the problems associated with performance of weak engineering soils due to poor resistance of these soils to shear deformation, low bearing capacity and excessive vertical compression, (Shakri et al., 2014). Most of the previous studies on deep mixing improved soils (Broms, 1979; Kawasaki et al., 1981; Kamon and Bergado, 1992; Walker, 1994; Schaefer et al., 1997; Lin and Wong, 1999; Fang et al., 2001; Porbaha et al., 2012; Yin, 2001; Porbaha, 2012; Farouk and Shahien (2013); Tao, Jim and Jing, 2014 etc.) have been based on performance of cement and lime/cement improved soils. There are limited consideration of wastes (by-product) material inclusion such as PFA and GGBS in deep soil mixing.

Undoubtedly, this method has been widely employed in the construction field for strength enhancement and improved compressibility especially, cement deep soil mixing, (Abbey, Ng'ambiand Ngekpe, 2015). Lately, problems particularly associated with cost and the environments have emerged. For this reasons, investigation into possible inclusion of waste (by-product) materials and reduction in cement content during deep soil mixing was investigated. According to Gyanen, Savitha and Krishna (2013),better soil gradation, increase in strength and reduction in plasticity properties are the most likely achievable results in the use of additives like GGBS and PFA in soil improvement. Ailin, Hafez and Norbaya, (2011), stated that Ca2+ exchange and pozzolanic reaction in PFA could lead to increase in strength of stabilised clay.The increase in strength over time may also be due to the possibility of suction development in pore fluid as a result of partial saturation of the improved samples after curing (Hemant and Mahendra, 2015).Increase in percentage of GGBS can lead to considerable reduction in pavement thickness, (Ashish et al., 2014) during improvement of subgrade materials. However, these studies have not stated clearly, the applicability of these by-products in deep soil mixing and their effect on soil type in terms of plasticity index.

2. METHODOLOGY

In the ongoing study, five soil samples with natural plasticity index ranging from 5% -45% were studied. The waste materials used were Pulverised Fuel Ash (PFA) and Ground Granulated Blast Slag (GGBS). Table 1.0 shows X-Ray Fluorescence result of the chemical compositions of Cement, PFA and GGBS.

Table 1.0 Chemical composition of Cement, PFA and GGBS.

Binder	Oxides (%)											
	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	SO_3	LOI
CEM I	19.63	0.26	4.71	3.25	0.09	1.17	64.09	0.27	0.73	0.20	2.94	3.22
PFA	52.15	0.87	19.61	7.10	0.07	2.00	4.40	1.06	1.93	0.45	0.54	9.48
GGBS	33.28	0.57	13.12	0.32	0.316	7.74	37.16	0.33	0.474	0.009	2.21	4.42

In order to investigate the effect of cement, and inclusion of PFA and GGBS on the plasticity of deep mixing improved soils, three categories of improved materials were considered, namely; Cement, Cement/PFA and Cement/PFA/GGBS improved soils. For the cement improved soils, cement contents of 5%, 10%, 15% and 20% by weight of dry soil were used. 5% cement content for soils1, 2 and 3 have not been considered due to available quantity of these materials. For the Cement/PFA improved materials, cement content was reduced by 50% and replaced with equal amount of PFA. The cement content was further reduced to 33.33% and replaced with equal amounts of PFA and GGBS to produce Cement/PFA/GGBS improved soil materials. In all, the total percentage of binder was kept constant, summing up to 5%, 10%, 15% and 20%. Wet deep soil mixing was conducted using water to binder ratio of unity. Physical properties of natural soils where first determined prior to mixing and soils were classified using the USCS as shown in Table 2.0.

Table 2.0 Soil classification parameters of natural soils

Soil Properties	Symbol	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5
Moisture content (%)	w	86	45	36	61	54
Liquid limit (%)	LL	68.0	41.66	45.16	87	63.12
Plastic limit (%)	PL	30.83	36.67	30.1	42.3	53.20
Plasticity index	PI	37	5	15	45	10
Unit weight (kN/m^3)	ϒ	25	23	22	24	21
Specific gravity	G	2.55	2.35	2.24	2.45	2.14
Unified classification	USCS	CH	ML	MI	MH	MH

3. LABORATORY TESTING

In this study, Atterberg limit test was conducted on five different soil types, improved using cement, Cement/PFA and Cement/PFA/GGBS based on procedures outlined in the British Standard (BS 1377-2:1990). The liquid and plastic limit tests were conducted on each percentage of binder, 3 days after mixing.

4. RESULTS AND DISCUSSION

The analysed results plotted in Figures 5.1(a, d and e), showed that the liquid limit of Soil 1, 4 and 5 decreases and plastic limit of Soil 4 increases and drops at cement content greater than 15%. Plastic limit of Soil 5 decreases initially and picks up with increase in percentage of cement. The liquid and plastic limits Soil 2 and 3increases as cement content increases as shown in Figures 5.1 (b and c). Grytan et al., (2012), attributed change in Atterberg limit properties of cement treated soils to cation exchange reaction and flocculation aggregation due to cement increase.

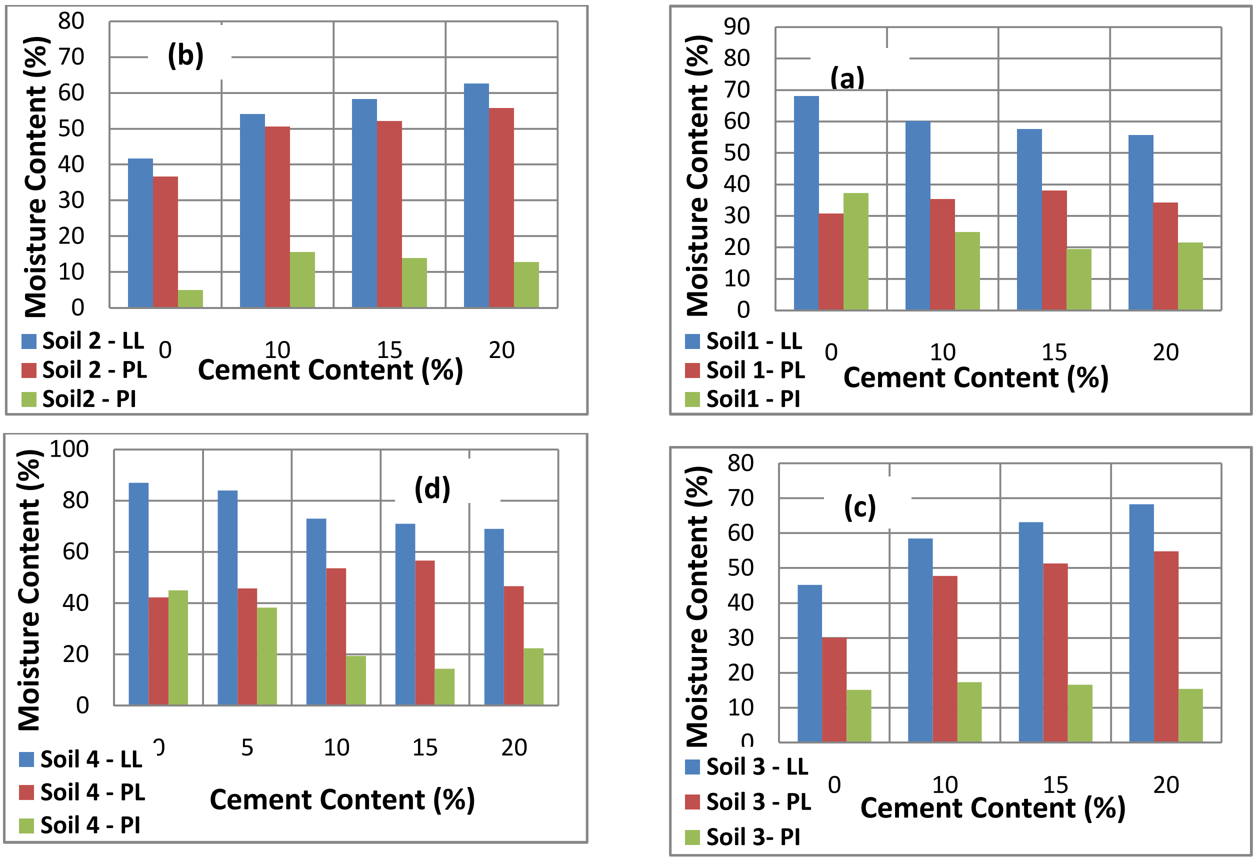

Figure 5.1(a, b, c, d) Cement deep mixing improved soil 1, 2, 3 and soil 4

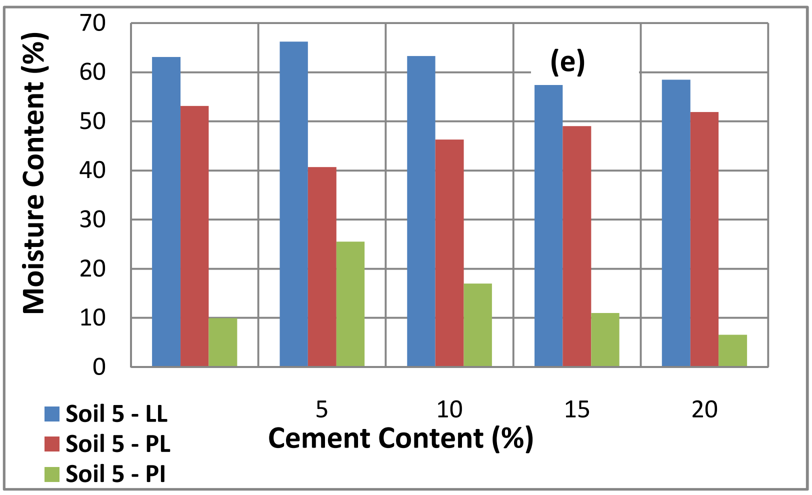

Figure 5.1(e): Cement deep mixing improved soil 5.

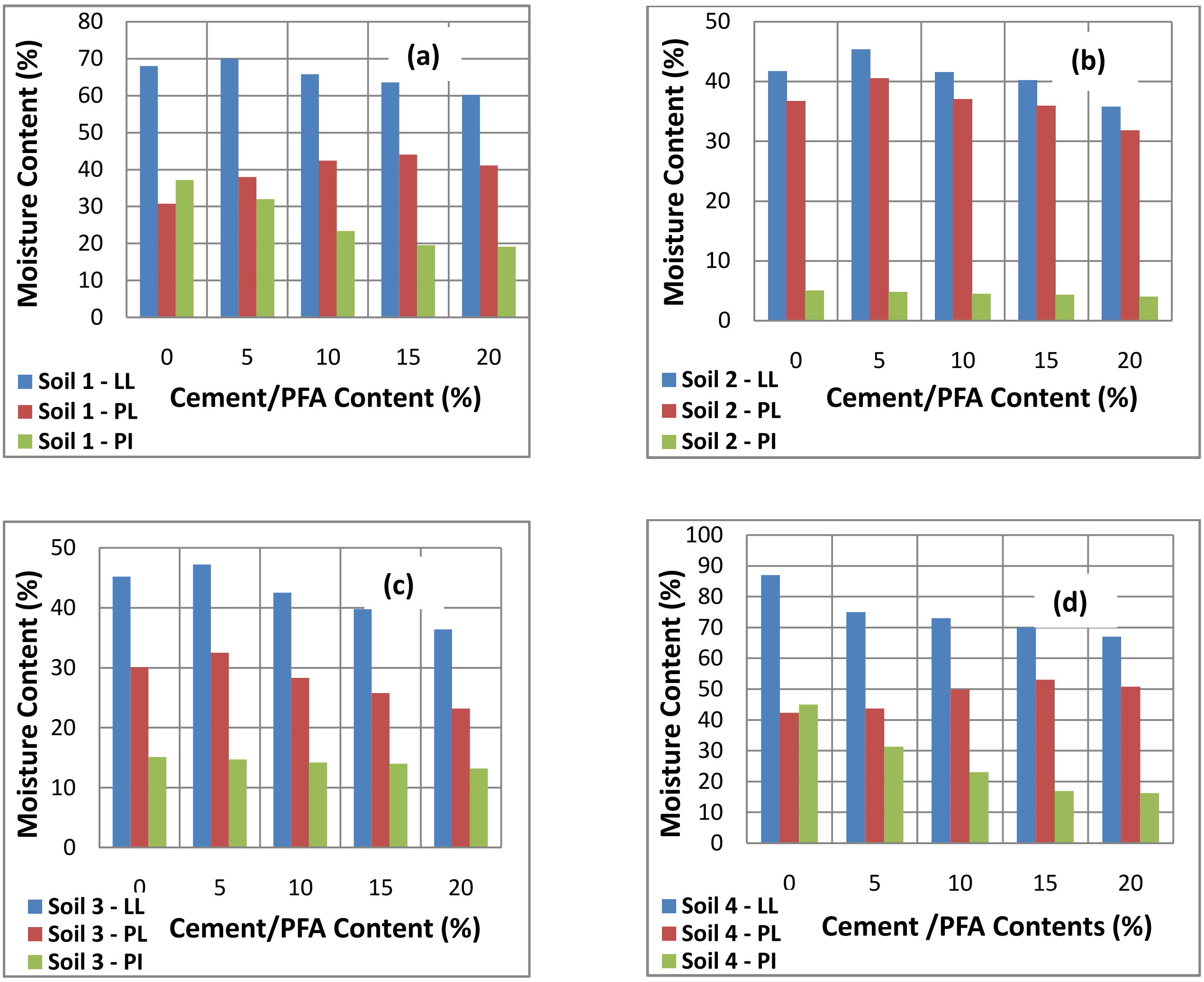

Figure 5.2 (a, b, c, d) Cement/PFA deep mixing improved soil 1, 2, 3 and soil 4.

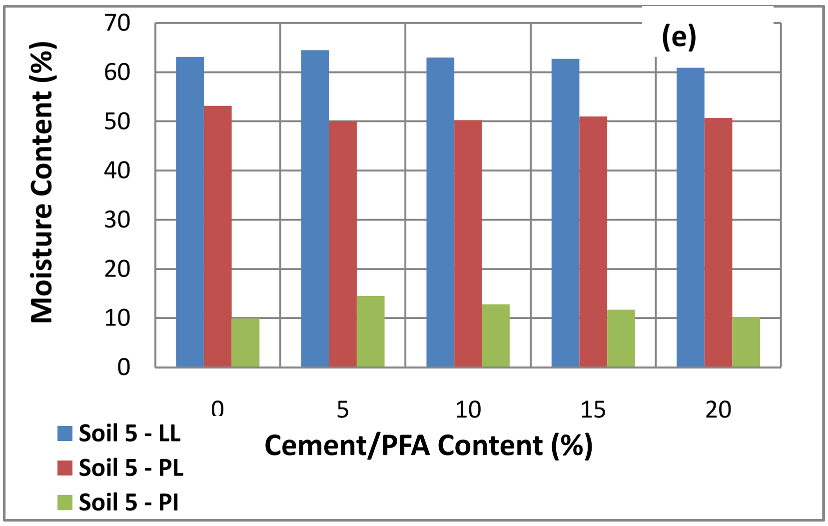

Figure 5.2 (e) Cement/PFA deep mixing improved soil 5.

On reduction of percentage of cement by 50% and inclusion of corresponding amount of Pulverised Fuel Ash (PFA), the liquid limit of Soil 1, 2, 3, and 5 increases initially due to addition of 5% cement/PFA content and then decreases with increase in Cement/PFA content as shown in Figures 5.2 (a, b, c, and e). From Figure 5.2(d), the liquid limit of Soil 4 decreases linearly with increasing cement/PFA content.

Plastic limit of Soil 1 and 4 increases and dropped slightly at 20% Cement/PFA content. While in Soil 2 and 3, plastic limit increases initially at 5% Cement/PFA content and drops linearly. While in Soil 5, plastic limit drops at 5% Cement/PFA content and remained almost linear up to 20% Cement/PFA.

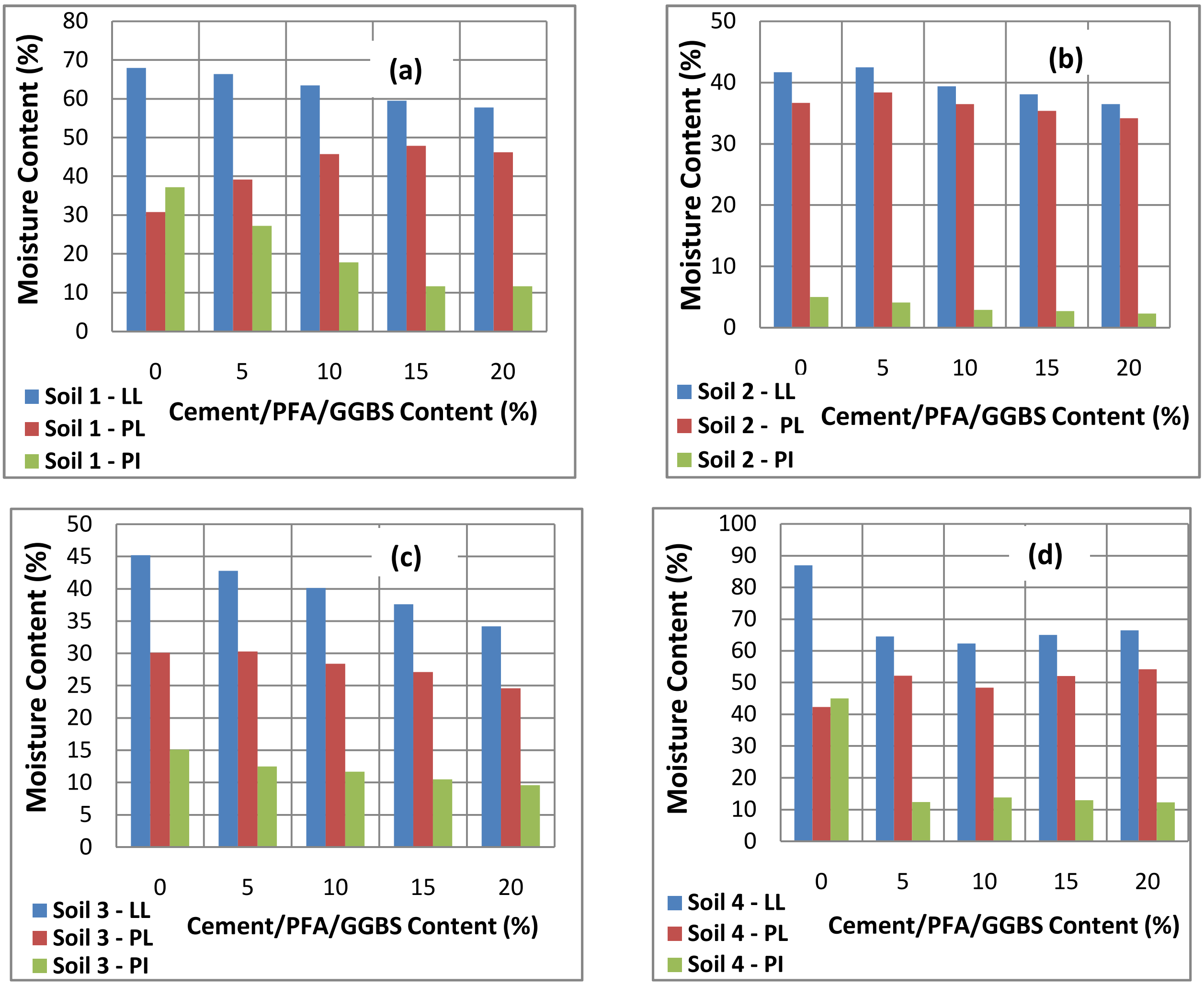

Figure 5.3(a, b, c, d) Cement – PFA - GGBS deep mixing improved soil 1, 2, 3 and soil 4.

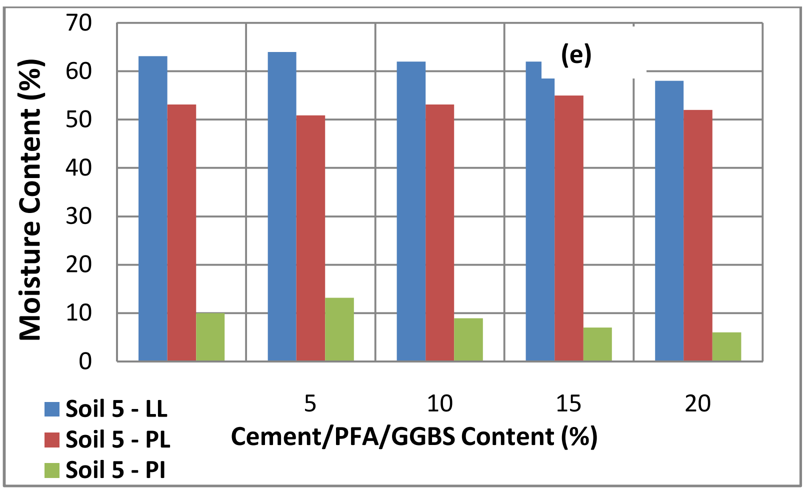

Figure 5.3 (e) Cement – PFA - GGBS deep mixing improved soil 5.

Further reduction in percentage of cement to 33.33% and replacement with equal amounts of PFA and GGBS resulted to a reduction in liquid limits of improved Soil 1, 2 and 3 as shown in Figure 5.3a-c. The plastic limit of Soil 1 increases linearly with increase in Cement/PFA/GGBS content. Plastic limit of Soil 2 increases initially on addition of 5% Cement/PFA/GGBS content then decreases linearly. In soil 3 the plastic limit decreases as Cement/PFA/GGBS content increase. From Figure 5.3d, plastic limit of soil 4 also, increases initially on addition of 5% Cement/PFA/GGBS and reduces at 10% binder content and increases linearly. From Figure 5.3e, the plastic limit of Soil 5 reduces slightly on addition of 5% Cement/PFA/GGBS and increases between 10% -15% and reduces at 20% Cement/PFA/GGBS content. Studies have revealed that different researchers have different opinions on the effect of increase in binder content on liquid and plastic limits of improved soils. Kezdi, (1979), stated that decrease in liquid limit, increases plastic limit. Both situations were observed in this study but on the average, an increase in cement paste in the mixture tends to reduce the fluidity of improved soils and increases the plastic limit but these also, appears to be dependent on the initial properties of the natural soil. It might therefore be more appropriate to describe improved soils based on their plasticity indexes. In terms of strength development, it is expected that the plasticity index of the improved soil decreases with increase in binder contents. Figure 5.4, 5.5 and 5.6 show plots of plasticity index of improved soils against varying binder content for all five soil types with different natural plasticity index of 5%, 10%, 15%, 37% and 45%.

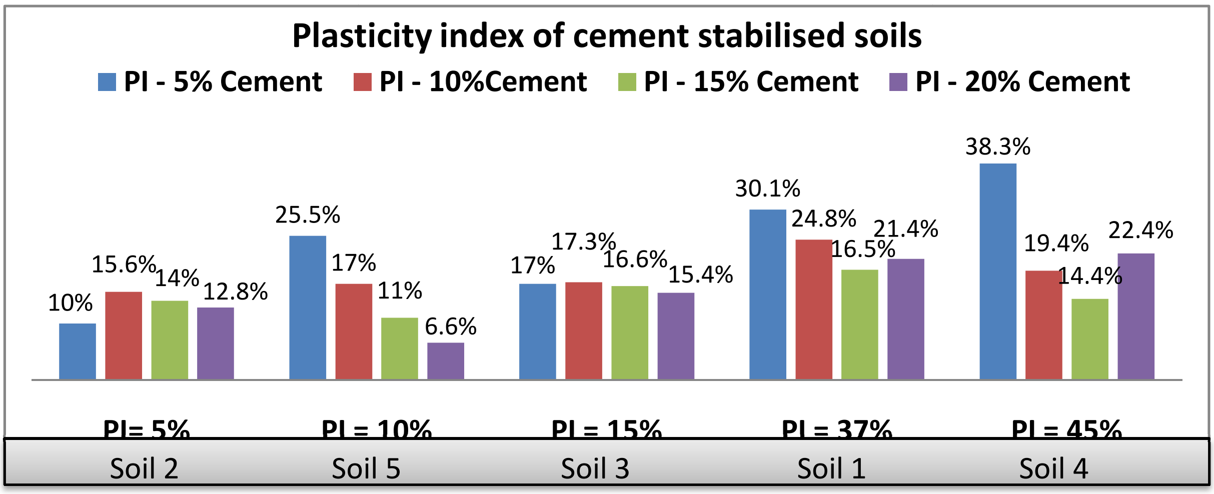

Figure 5.4 Plasticity index of Cement improved soil for different soil types

The analysed results plotted in Figure 5.4, 5.5 and 5.6 shows the plasticity index (PI) of the natural soils and variations of the plasticity index of their improved materials with binder type and content. Figure 5.4 shows that soils with natural plasticity index between 5%-15% showed almost linear decrease in plasticity index as the percentage of cement increases up to about 20%, except for Soil 2 (PI=5%)which shows initial increase in plasticity for 5 to 10% cement due to low plasticity of the natural soil and insufficient cement paste. Balasingam and Farid (2008) reported a decrease in plasticity index of cement stabilised soil with natural plasticity of about 11.4%. However, for soils with 37% - 45% natural plasticity index, increase in cement content above 15% by weight of dry soil causes an increase in plasticity index of the improved soil and this has significance on the strength gain of the improved material. In a research and development bulletin released by the US Portland Cement Association, it was stated that for soils with natural plasticity index between 37 to 42%, that performance of the soils improved significantly upon addition of 6 to 9% cement content. However, the current study has shown that increase in cement content beyond 15% causes point of inflexion on plasticity index of cement improved soils. This could indicate the amount of cement needed for optimum performance in terms of improvement of properties of soils with natural plasticity index between 37 to 45%. These could cause the use of cement alone for cement content ≥15% by mass of dry soil, unsuitable for deep soil mixing of soils with natural plasticity index ≥ 37%. Similar trend is observed in results of soils improved with PFA and PFA/GGBS inclusion for soils with natural plasticity index less than 15% irrespective of the binder percentage as shown in Figure 5.5 and 5.6 respectively. However, for soils with natural plasticity index greater than 37%, the plasticity index of the improved soil does not increase with increase in binder percentage beyond 15% and at 20% as observed previously for cement only.

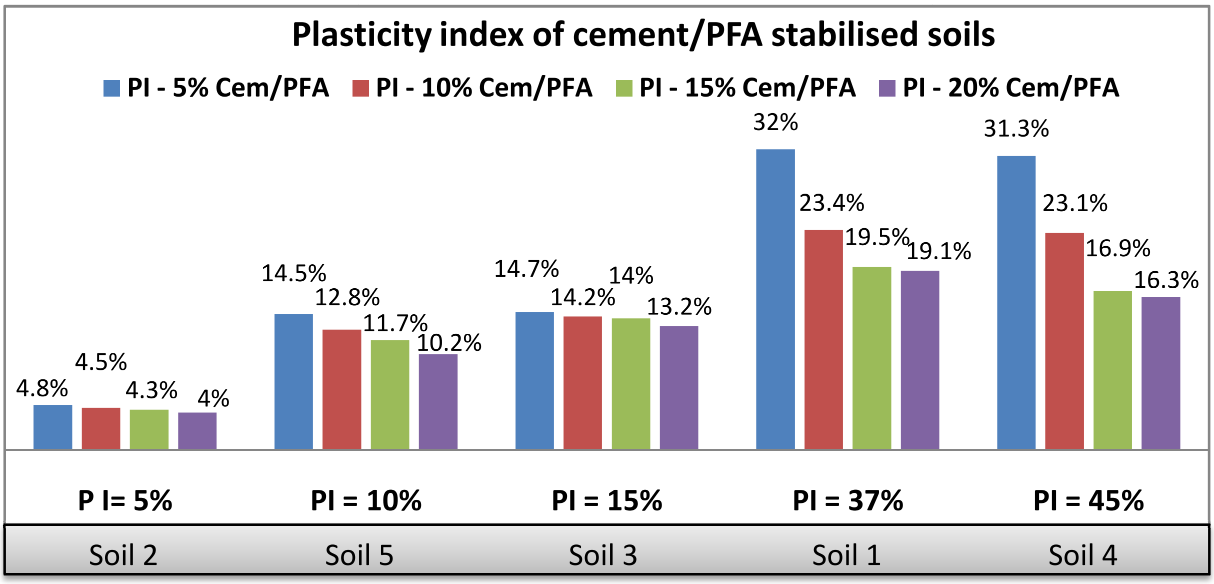

Figure 5.5 Plasticity index of Cement/PFA improved soil for different soil types

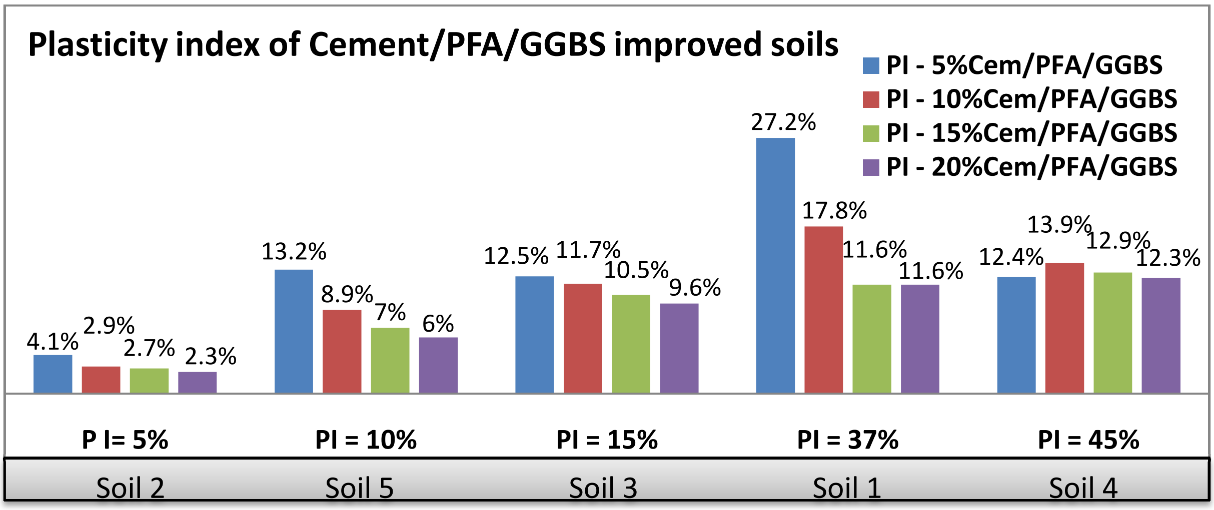

Figure 5.6 Plasticity index of Cement/PFA/GGBS improved soil for different soil types

The results have shown that 15% cement is the optimum amount of cement required for deep mixing improvement of soils with natural plasticity index of 5-45%. The inclusion of GGBS and PFA in the blended soil reduces the amount of cement required for optimum binder content and resulted to 20% Cement/GGBS/PFA optimum binder content in the ratio of 1:1:1. This study has shown that addition of 15% cement content and 20% Cement/GGBS/PFA resulted to improved soils with plasticity index less than 17% making the investigated soils suitable for use as embankments and pavement for light to medium traffic, (Ashish et al. 2014). Interestingly, it has been observed that soil-binder interaction varies with soil type and the extent of improvement in plasticity index is also dependent on the plasticity index of the natural soil. This implies that it might be impractical to set a common precedence applicable to all binder types. However, a generalised flow chart based approach as a function of plasticity index of the natural soil can been developed for selection of binder for use in construction where increase in strength is envisaged, as shown in Figure 5.7.

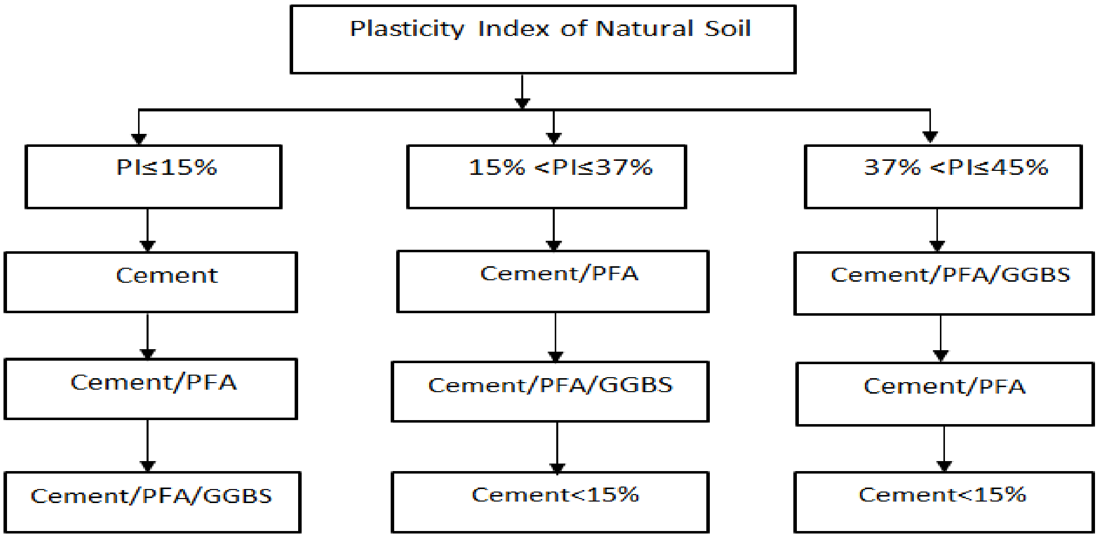

Figure 5.7 Deep soil mixing decision flow chart for selecting binders for use in construction

5. CONCLUSION

- On the average, reduction in plasticity index of the cement improved soils were found to be less when compared to Cement/PFA and Cement/PFA/GGBS improved soils especially for soils with natural plasticity index within the range of 37% to 45% respectively.
- The reduction in plasticity index of the improved soils due to PFA and GGBS inclusion may possibly indicate that irrespective of the plasticity index of the natural soil, PFA or PFA+GGBS could be used with reduced amount of cement during wet deep soil mixing.
- The plasticity index of Cement/PFA improved soils appears slightly higher than that of Cement/PFA/GGBS. This might be due to increase in cementation effect as a result of inclusion of GGBS.

This study has shown that addition of PFA and GGBS to cement during deep soil mixing can reduce the plasticity index of the improved soil and consequently, enhance strength gain of the improved material over time. This implies that, PFA and GGBS could be used in deep soil mixing with reduced amount of cement and thus reducing cost, CO_2 emission and environmental impact of cement deep soil mixing.

REFERENCE

[1] Abbey, S.J., Ng'ambi, S., and Ngekpe, B.E., (2015) 'Understanding the Performance of Deep Mixing Improved Soils - A Review' International Journal of Civil Engineering and Technology, Vol. 6, 3 pg 97-117.

[2] AilinNur J.O., Hafez, M.A., and Norbaya, S., (2011) 'Study of Bearing Capacity of Lime-Cement Columns with Pulverised Fuel Ash for Soil Stabilization using Laboratory Model' Engineering Journal of Geotechnics and Environment, Vol. 16 pg 1595-1605.

[3] Ashish, K.P., Pandey, V., Krishna, M., and Singh, J.P., (2014) 'Soil Stabilisation using Ground Granulated Blast Furnace Slag' International Journal of Engineering Research and Application, Vol. 4, 5 pg 164-171.

[4] Bhattacharja, S., and Bhatty, I. J. (2003) 'Comparative Performance of Portland Cement and Lime Stabilization of Moderate to High Plasticity Clay Soils'. Research and Development Bulletin RD125.

[5] Broms, B. and Boman, P. (1979) 'Lime columns – a new foundation method.' ASCE, Journal of Geotechnical Engineering 105, 539-556.

[6] British Standard Institution (BS) 1377 (1990) "Methods of Test for Solls for Civil Engineering Purposes.

[7] Farouk, A., and Shahien, M.M. (2013) 'Ground Improvement using Soil-Cement Columns: Experimental Investigation'. Journal of Alexandria Engineering, 52 (4) 733-740.

[8] Grytan, S. Rafiqul, I., Muhammed, A. and Rokonuzzaman, M. (2012) 'Study on the Geotechnical Properties of Cement based Composite Fine-grained Soil'. International Journal of Advanced Structures and Geotechnical Engineering Vol. 01, 02 pp 42-49.

[9] Hemant, S.C., and Mahendra, K.V., (2015) 'Strength Characterisation of Fibre Reinforced Cement-Fly Ash Mixes'. International Journal of Geosynthetics and Ground Engineering, Vol. 1, No 30 pp 1-8.

[10] Kamon, M. (1997). 'Effects of Grouting and DMM on Big Construction Projects In Japan and the 1995 Hyogoken - Nambu Earth Quake.' Proceedings of ISTokyo'96, 'The 2nd International Conference on Ground Improvement Geosystems'.held 14-17 May 1996 at Tokyo, Balkema : 807-824.

[11] Kezdi, A. (1979) 'Soil physics'. Elsevier Scientific Publishing Company, Amsterdam.

[12] Naieni, S. A., and Ziaie, M., (2009) 'Effect of Plasticity Index and Reinforcement on the CBR Value of Soft Clay'. International Journal of Civil Engineering, Vol. 7, 2 pp 124-130.

[13] Porbaha, A. (1998) 'State of the art in deep mixing technology, Part I: Basic concepts and overview of technology.' Ground Improvement, 2 (2), 81-92.

[14] Nagendra Prasad.K, Manohara Reddy.R, Chandra.B and Harsha Vardhan Reddy.M, "Compression Behaviour of Natural Soils". *International Journal of Civil Engineering and Technology (IJCIET)*, 4(3), 2013, pp.80–91.

[15] Porbaha, A., Tanaka, H. and Nazri, A. (2012) 'State of the art in deep mixing technology, Part II: Applications. ' Proceeding of the ICE on Ground Improvement'. July 1998, (2) 125-139.

[16] Shakri, M.S., Hafez, M.A., Adnan, M.A., and Nazaruddin, A.T., (2014), 'Effect of use of PFA on Strength of Stone Column and Sand Column'. Engineering Journal of Geotechnics and Environment, Vol. 19 pp 3745-3755.

[17] Dr. K.V.Krishna Reddy, "Correlation between California Bearing Ratio and Shear Strength on Artificially Prepared Soils with Varying Plasticity Index". *International Journal of Civil Engineering and Technology (IJCIET)*, 4(6), 2013, pp.61–66.

[18] Tao, Y., Jin, Z.Y. and Jing, N., (2014) 'Analytical Solution for the Consolidation of a Composite Ground Reinforced by Partially Penetrated Impervious Columns'. Journal of Computers and Geotechnics 57 30-36

[19] Wild, S., Kinuthia, J.M., Robinson, R.B., and Humphrey, I., (1996) 'Effect of Ground Granulated Blast Furnace Slag (GGBA) on the Strength and Swelling Properties of Lime-Stabilised Kaolinite in the presence of Sulphates' The Mineralogical Society, Vol. 31 pg 423-433.