Determination of an Optimum Curing Age for Sub-grade Soils Stablised with Ordinary Portland Cement

Hashim Mohammed Alhassan*, Murtala Garba**
*(Department of Civil Engineering, Bayero University Kano, 700241, Gwarzo Road, Nigeria.
** (Works Department, Gwarzo Local Government , Kano State, Nigeria.

ABSTRACT

This research was aimed at predicting an optimum curing age for cement stabilised subgrades ahead of the seven (7) day curing period prescribed in specifications. An existing road with a record of persistent failures was investigated for possible subgrade stablisation. Four trial pits at chainages 0+010, 0+200, 0+350 and 0+475 were dug and samples were taken for testing using the standard testing methods. The subgrade material was classified as A-3 and A-4 under the AASHTO and Sandy Silt (SM) in the Unified Soil Classification System. Stablisation using varied contents of Ordinary Portland Cement up to 12% improved the strength dramatically. Curing at the ages of 3, 5 and 7 days indicated that the 5day curing age strength surpassed the 7 day strength quoted in the specifications. The mixing efficiency of not less than 60% of the Laboratory values may be required to be applied to the field values in the mix design. However, to get the required design strength prior to 7 days curing period prescribed in the specification, a cement content of 8% appears to be optimal. This design strength was met at 5 days. This will allow 2 days of work prior to mix design specification. Thus there is a reduction of two days within which construction works can proceed without prejudice to specifications and the quality of work. The Laboratory test will need to be factored to give the required field strength and a factor of 0.6 is therefore suggested.

Keywords – **Compactive Effort, Curing, Soil-cement, Sub-grades, Compressive Strength, Field Strength.**

I. INTRODUCTION

Cement-soil stabilization is utilized in diverse engineering development projects such as building pads, container ports, warehouses, rail and truck terminals, parking areas, truck docks, materials handling and storage areas and composting facilities among others. Cementitious materials like cement are commonly used to stabilize weak sub-grade soils in order to increase their stiffness, shear strength. The increase in the engineering properties results in overall improvement in the performance of both rigid and flexible pavements. In the case of flexible pavements, sub-grade stabilizations result in reduction of rutting, fatigue and longitudinal cracking. The current state of practice is primarily based on laboratory testing to determine the type and the amount of stabilizer required for a given situation. Particle size analyses and Atterberg limits tests are used to select the type of stabilizer. The unconfined compressive strength test is used to determine the amount of time the stabilizer requires to achieve a predetermined design strength based on a 7-day curing period.

One major shortcoming of the current state of practice is that there is no easy and reliable field test that can be used in the constructed stabilized sub-grade after the 7-day curing period. Therefore design strengths cannot be verified prior to allowing heavy construction equipment to operate on the stabilized sub-grade. In an attempt to address this shortcoming, agencies have developed very detailed construction specifications, usually addressing methods of measuring rates of application, efficiency of pulverization, depth and uniformity of mixing, thickness of compacted layer, density, moisture control, quality of cementitious materials and construction equipment required to execute the work. This approach has several shortcomings, first there is no assurance that the finished product will have the required design strength at the end of the 7-day curing period, even if the contractor strictly adhered to the specifications. Secondly, there is no way of detecting when the design strength has been achieved prior to the 7-day curing period. This is very critical because there is tremendous pressure to speed up construction. Thirdly, the current practice requires considerable oversight from the agencies. Most agencies are experiencing budget shortfalls and this is resulting in a reduction in the number of employees. Therefore, there is a need to reduce oversight and depend more on measuring the performance of the finished product, which should require less manpower because the amount of inspection is greatly reduced. Finally, the present practice places most of the liability on the agencies. This is because the agencies direct construction procedures and if the contractors adhere strictly to the specification, they cannot be held accountable for the finished product.

The development of a strategy test that can directly or indirectly indicate the strength of a soil-cement mixture will go a long way in addressing these issues. Knowing these, engineering properties will allow verification of design pavements and as a consequence expect improvement of pavement performance. In-situ testing will greatly simplify contract administration, because the only thing each agency inspector will have to do is verify the strength and depth of stabilized sub-grade. This should reduce agency manpower requirements. It will also shift the liability of achieving the desired performance properties to the contractor. This should provide incentive to the contractors to be innovative and to use sound construction practice.

Furthermore, this should facilitate faster construction because the strength can be monitored daily and as soon as the design strength is achieved, the contractor can be allowed to operate heavy equipment on the stabilized sub-grade. This could result in considerable cost savings because contractors will not have to wait for 7 days if the strength requirement have been made earlier and will greatly reduce the likelihood of failure due to the design requirements having not been achieved at 7 days. In many cases, therefore the time required to deliver projects will be shortened and this should be reflected in lower bid prices. In all cases, there will be assurance that the as-constructed properties of the stabilized sub-grade are as specified. This paper aims to investigate if the strength of cement-soil mixes can be obtained ahead of the 7-day curing age strength given in the specifications. The rest of the paper is organised as follows: section 2 reviews the literature on the subject, in section 3.0 the materials and methods used are explained. Section 4 presents the results and discussion and the conclusions are stated in section 5.

II. LITERATURE REVIEW

Cement application in soil stabilization is about 5 decades old. Cement stabilization is commonly used in the improvement of flexible pavement layers during construction. Many different materials, having similar properties to cement have equally been used in soil stabilization. Commonly used stabilizers include Lime (Al-Rawas, Hago and Al-Sarmi, 2005), Hay fibre (AbdulMageed, 2013), waste paper sludge ash (Mohamad and John M., 2011), gypsum (Nurhayat, Arzu and Ayse, 2007) Rice husk ash (Basha et al., 2005), Solid waste Incinerator bottom ash (Alhassan and Ahmed, 2012), organic polymers (Jin et al., 2011), and combinations of these (Al-Rawas, et al., 2005). Adding stabilizing agents to soils, brings about a sequence of reactions such as pozzolanic reaction, cation exchange, flocculation, carbonation, crystallization, and dissociation (Zhi-Duo and Song-Yu, 2008). These processes strengthen the coupling between grains and fill up the voids in soils and as a result, this improves the engineering properties of the soils, such as strength and stiffness. The reactions occurring between stabilizing agents and soils are also related to the type of soil. Some stabilizing agents are particularly suited for stabilizing clay soils, however, the silts stabilized by such stabilizing agents usually do not meet the requirements for road construction. They present problems such as lower early strength, greater shrinkage, easy cracking, and bad water stability (Abdullah and Al-Abadi, 2010).

The cement hydration, during the stabilization process is responsible for the strength gain. It is therefore imperative to make water available for the curing of the mix, but this is also accompanied by water evaporation and re-arrangement of particles within the mix, resulting in a decrease in the stabilized mix volume and in the development of internal strains. The internal strain in early age mixes is known as shrinkage strain and is responsible for the small cracks appearing after the curing process (Andre et al., 2012). Observing the cement-soil mixture during the curing process is highly important in large infrastructures, such as roads. This is necessary because a rigorous control of the curing process allows an improved material, resulting in the optimization of the construction planning. The cure monitoring is also important for operations in adverse weather conditions such as snow, high rainfall or high relative humidity

Monitoring of curing has been applied in a number of novel concrete production using waste plastic products. For instance, (Silver, de Brito and Nabajyoti, 2013) considered the effect of curing conditions on the durability of concrete mixes containing selected plastic waste aggregates. Concrete mixes were prepared in which 0%, 7.5% and 15% of natural aggregates were replaced by plastic–polyethylene terephthalate (PET)–aggregate. The test results showed a decline in the properties of concrete made with plastic aggregates, in terms of durability, compared with conventional concrete. All specimens performed worse when subjected to drier curing regimes. However, sensitivity analyses showed that the properties of concrete mixes containing plastic aggregates generally deteriorate less than those of conventional concrete, when subjected to progressively drier curing regimes (Silver, et al., 2013) .

In another work, (Al-Gahtani, 2010) examined the effect of curing methods on the properties of plain and blended cement concretes. The concrete specimens were cured by covering with wet burlap or by applying two types of curing compounds, namely water-based and acrylic-based. The effect of curing methods on the properties of plain and blended cement concretes was assessed by measuring plastic and drying shrinkage, compressive strength, and pulse velocity. Results indicated that the strength development in the concrete specimens cured by covering with wet burlap was more than that in the specimens cured by applying water – and acrylic-based curing compounds.

Other works on the curing conditions and age of concrete or cement stabilized mixes include (Wang, Dhir and Levitt, 1994) on membrane curing; (Ferreira, de Brito and Saikia, 2012) who studied curing conditions on performance of concrete with some selected plastic waste aggregates; (Turkmen and Kantarci, 2006) on the effect of curing conditions on the drying shrinkage of self-compacting concrete; (Amorin, de Brito and Evangelista, 2012) on the influence of curing on durability of concrete made with coarse concrete aggregates and (Safiuddin, Raman and Zain, 2007) on the effect of differing curing methods on the properties of micrsilica concrete. Quite clearly, studies that focused on obtaining optimal curing age for both cement-soil mixes and concrete for field applications are sparse.

III. MATERIALS AND METHODS

Twenty samples of soil from four hand dug pits at chainages 0+010, 0+200, 0+350 and 0+475 of Kano-Madobi Highway known for its persistent failures were collected for this study. The depth of excavation and description of the samples is shown in Table 1. Two to three horizons of soil profiles per pit were taken for detailed study. The lithology of the soils is red to brown in trial pits 1 but changes to gray and shades of gray in pits 2, 3 and 4. This shows the soils may have been taken from different burrow pits during construction. Atterberg and compaction tests were carried out on the samples to confirm if they meet the requirements for use as road construction materials. In particular, they were tested for suitability in subgrade construction in accordance with (British Standard Institution, 1990) and FMWH(1997).

A. Cement

Fresh Ordinary Portland Cement obtained from Ashaka Cement Company Nigeria Limited was used as a binder in the present investigation with compressive strength values of 40.03 and 50.94 MPa after 7 and 28 days respectively, as indicated by the supplier.

B. Soil-Cement Mixtures

A 20kg weight of soil from each of the four samples were air dried and the air-dried moisture content determined. The soil was then quartered until eight batches each of about 2kg were obtained. Suitable quantities of water were then added to the soil to enable a range of moisture contents covering the probable optimum moisture content. The soil was then mixed with water and the damp soil stored for 24hours in an airtight container to enable the moisture to become uniformly distributed throughout the soil samples. Four out of the eight portions of each soil sample was mixed with 4%, 6%, 8% and 12% Cement and the fifth one was left in its natural state to serve as a control. The samples are prepared in the standard CBR mould using five layers, each layer being given 62 blows using the 4.53 kg rammer. The surface area of the plunger is 19.3cm^2 with the rate of penetration of 1.27 mm per minute (British Standard Institution, 1990).

C. Compressive Strength Test

Three specimens were made from the five soil-cement mixes for each of the soil samples. The specimens made were cured after coating the surfaces with a layer of paraffin wax to keep the moisture content constant and were stored in a room where the temperature is fairly uniform. Three specimens from each mix were tested at 3days, 5days and 7days after curing in a standard water bath.

D. Field Pilot Test.

To closely monitor the development of strength with curing age under field conditions, a 50m section of the road which is 7.3m wide was selected for stablisation. The base and sub-base material was removed to meet the sub-grade soil; the sub-grade material was then tilled to a depth of 0.4m using a mechanical pulveriser.

E. Mix Method

The batch mixer method was employed in the field tests. This was done using a concrete mixer. The subgrade soil was batched by volume. Tests carried out at Transport and Road research laboratory (TRRL), (Bofinger, 1978) and (Portland Cement Association, 2001), suggests 8-12% cement for silty soils. Therefore 8% cement content was adopted in this test. To every 100kg of the subgrade soil 8kg of cement was added and a quantity of water equivalent to the optimum moisture content of the material obtained in the laboratory test was added and mixed until a uniform mixture was obtained. The mixture was then spread and compacted using a smooth faced roller.

Figure 1.0: Field Compaction of the Test Area.

F. Field Control Tests

Three field control tests were carried out during the field pilot test in the soil-cement stablisation. These are the sand bath method for moisture content determination, compaction test for compressive strength determination and core-cutter method for in situ density determination. All the tests being in accordance with (British Standard Institution, 1990) methods.

IV. RESULTS

The particle size analysis characteristics of trial pit 1 located at chainage 0+010 RHS has about 36.45 percent passing the No. 200 sieve size, giving consistency limits of 20.10 for liquid limit, 15.20 for plastic limit, with a plasticity index of 4.90. The soil at CH 0+010 is therefore classified according to AASHTO as A-4 soil. A-4 soils are generally not suitable directly as road subgrades and/or sub-bases. They may need to be stabilized mechanically for strength improvement. The optimum moisture content value of 9.20 and maximum dry density of 1.91 indicates that high moisture content values are likely to reduce the strength. The trial pit No.2 sample taken at *CH 0+200 CL* points to a similar trend as trial pit No.1. The significant difference being that trial pit No.2 sample can withstand much higher value of moisture content. Samples taken at trial pit No.3 and 4 at chainages 0+350 LHS and 0+475 respectively also exhibit similar trends. Both are non plastic soils and falls under A-3 AASHTO classification. Trial pit No.4 samples have higher moisture content with a slightly lower dry density compared to trial pit 1. Thus all the samples tested are marginal soils and may be responsible for the persistent failures recorded on the road. A summary of the soils characteristics is given in Table 2.0. The global average indicators for the soils along the road are 33.43 percent passing No. 200 sieve, Optimum Moisture content value of 11.30% and Maximum dry density value of 1.82. The soils could be described as non-plastic to plasticity index of 5.10 and classified under AASHTO as A-3 to A-4 soils.

Table 1.0: Description of Soil Samples

Trial Pit No.	Chainage	Natural Moisture Content (%)	Depth (m)	Lithological Description of Soil Strata	Remark
TP1	0+010 RHS	7.8	0 - 0.063	Slightly moist reddish laterite	Red
			0.063 - 1.2	Moist brownish silty sandy clay	Brown
TP2	0+200 CL	10.7	0 - 0.36	Slightly moist grayish laterite/Refuse	Gray
			0.36 - 0.62	Moist grayish laterite base and subbase	Gray
			0.62 - 1.2	Moist grayish silty sand	Gray
TP3	0+350 LHS	7.3	0 - 0.98	Moist grayish laterite	Gray
			0.98 - 1.2	Moist whitish silty sand	White
TP4	0+475 RHS	6.5	0 - 0.46	Moist grayish laterite base and subbase	Grey
			0.46 - 1.2	Moist light grayish silty sand	Light Gray

The results of the preliminary tests indicate that in general there was a reduction in optimum moisture content (OMC) and maximum dry density (MDD) with an increase in cement content, but at different rates as shown in Table 3. The soils in Trial Pits 1&2 behave in a similar manner and have much lower OMC values compared to soils from trial pits 3 and 4. There was an increase in optimum moisture content from 9.40 at 0% cement content to 9.50 at 12% cement content for TP1. This represents about 20%

reduction in optimum moisture content values. Similarly, moisture content reduction values for TP 2, 3 and 4 are 39.3%, 17% and 36% respectively. Therefore an average percentage reduction in OMC for all the samples is 28.07%. Reductions in OMC values may have obvious effects on strengths since less pore water will be available for the cement hydration process.

In a similar way, the MDD values were observed to reduce with increase in cement content. Thus average MDD values for the four sample locations at zero percent cement content are 1.92, 1.94, 1.94 and 1.98 respectively. With cement addition to 12% content, the MDD values reduce to 1.63, 1.76, 1.79 and 1.66g/cc respectively. The average percentage reduction values for all samples is 11.08%.

The strength characteristics for the trial pits samples generally indicate an increase in compressive strength with increase in cement content and curing age. Figures 2 to 5 show the variation of compressive strength with cement content for the trial pits studied. For zero percent cement content 13.5% increase (average) in strength was observed from 3 to 7days curing age for TP 1. For 4% cement content, the average percentage increase in strength from 3 to 7days was 27.3, 36.5, 55.9 and 60% increase in strength were recorded for 6%, 8% and 12% cement contents from the curing ages of 3 to 7days. Similar trends are observed in all the samples from TP2 through TP4.

The increase in cement content at a constant age of curing led to significant increases in compressive strength. Thus for 3-days curing the range of strength increase from 0% cement to 12% are 8.4%,16.9%, 29.5%, 14.1% for the four trial pits tested as shown in figures 5 to 8. Similarly, for the 5-Days curing age, 37.9%, 41.1%, 47.9% and 24.0% strength increases were observed for the four trial pit samples. The 7-days strength increment from 0% to12% cement content are 40.8%, 43%, 50% and 28.8%, it is therefore highly beneficial to stablise marginal laterites with cement. In general, therefore strength increases with increase in cement content and age of curing. The strength gain is attributed to the pozzolanic action of the cement which coats the surfaces of the soil body and reacts with water to form a hard strong nucleus. The higher the cement content the greater the pozzolanic effect and the higher the strength gain. As long as water is present in the pores of the soils, the hydration process will continue and strength gain will be enhanced.

Table 2: Grading and Atterberg Properties of Soils.

PROPERTIES/SAMPLES	TP1	TP2	TP3	TP4
	Depth 0.6-1.2m	Depth 0.6-1.2m	Depth 0.6-1.2m	Depth 0.6-1.2m
Specific Gravity	2.150	2.265	2.176	2.196
Nat. Moisture Content, %	7.80	10.70	7.30	6.50
OMC, %	9.20	14.70	9.20	11.30
MDD [Mg/m^3]	1.91	1.76	1.79	1.81
Un-soaked CBR, %	21.75	23.40	20.60	19.21
% Passing BS sieve No.3/4”	100	100	100	100
% Passing BS sieve No.3/8”	100	100	100	100
% Passing BS sieve No.1/4”	100	98.75	100	100
% Passing BS sieve No 10	96.75	97.95	99.50	99.20
% Passing BS sieve No.14	94.20	97.20	98.75	98.75
% Passing BS sieve No.25	93.10	95.50	97.05	97.30
% Passing BS sieve No 36	91.31	94.50	95.45	95.10
% Passing BS sieve No.52	42.15	92.65	94.30	92.85
% Passing BS sieve No.100	37.80	45.50	45.00	55.85
% Passing BS sieve No.200	36.45	35.60	28.30	33.43
Liquid Limit, %	20.10	18.20		
Plastic Limit, %	15.20	13.00	NP	NP
Plasticity Index, %	4.90	5.30		
AASHTO	A-4	A-4	A-3	A-3

Table 3: Laboratory Compaction Results

Cement Content (%)	***Trial Pit 1***		***Trial Pit 2***		***Trial Pit 3***		***Trial Pit 4***	
	OMC	MDD	OMC	MDD	OMC	MDD	OMC	MDD
0	9.40	1.63	10.7	1.76	10.00	1.79	12.50	1.66
4	9.20	1.81	9.30	1.81	9.30	1.88	12.10	1.72
6	8.50	1.83	8.70	1.89	9.20	1.90	10.10	1.78
8	8.40	1.89	8.20	1.89	9.20	1.92	8.70	1.83
12	7.50	1.92	6.50	1.94	8.30	1.94	8.00	1.89

Table 4: Average Strengths for Different Curing Ages and Cement Content

Curing age (days)	**Average Strength in N/mm^2 at Cement content (%)**				
	0	**4**	**6**	**8**	**12**
3	7.77	8.38	8.22	9.04	11.40
5	8.93	11.14	12.19	16.73	21.99
7	10.52	12.66	15.03	24.38	31.77

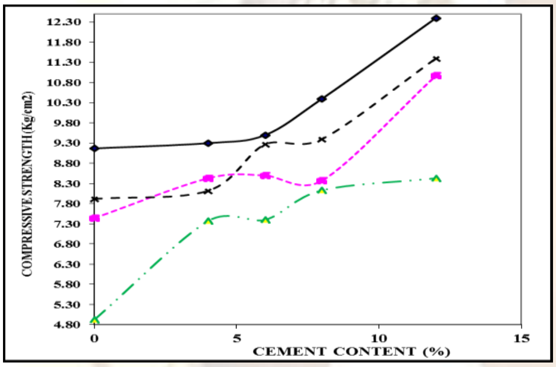

Figure 2: Compressive Strength against Cement content for TP 1

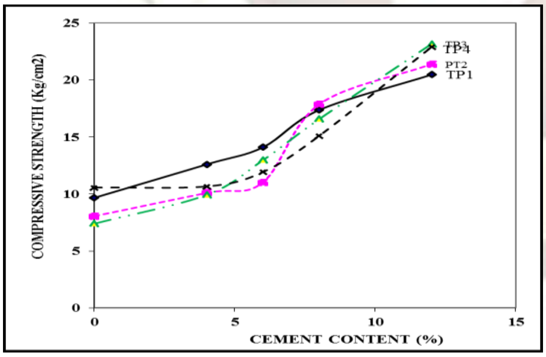

Figure 3: Compressive Strength against Cement content for TP 1

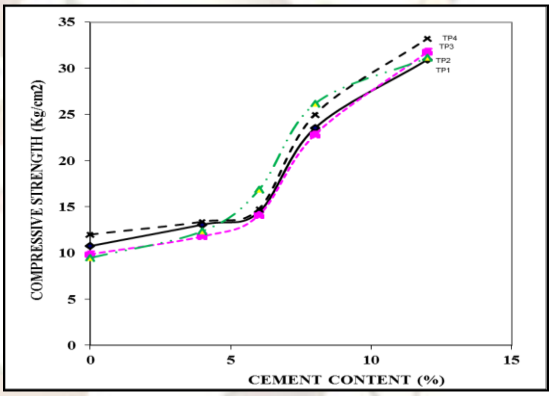

Figure 4: Compressive Strength against Cement content for TP 1

The criteria for soil-cement for road construction are:

1) Road subbase 3,500 – 10,500KN/m^2
2) Road base for light traffic 7,000 – *14,000KN/m^2*
3) Road base for heavy traffic 14,000 – *56,000KN/m^2*

FMWH (1997)

This study satisfied the criteria for items (1) and (2) and exceeding it for 5 days curing in all the trial pits. Considering Table 4 and relating it to the specifications quoted above, it can be seen that in the 5 days curing age strength attained surpasses minimum requirements.

In order to find suitable field identification methods that will measure the performance properties of subgrade soils, a test section was stablised using 8% cement content as described in section 3.4. Three methods were adopted in trying to monitor the performance of the soil-cement mixture. The aim in all cases was to predict the best age at which construction work could be ordered to commence before the 7-days specification usually used elapses. One way by which the quality of soil-cement mix could be predicted is to determine the dry density over the curing period to see at what age an optimum density will result in a consistent strength for construction work to continue. For the dry density over the three different curing periods, i.e. 3,5 and 7 days, 16,7% and 18.4% increase was observed between 3days and 7days curing respectively. Between the field and the laboratory dry densities marginal increase were observed. This is usual as laboratory samples are smaller and the relative compactive efforts higher. Comparison of the laboratory and field compressive strengths are shown in figures 9 to 12 for the four pits investigated.

Generally higher values of compressive strength were obtained for lab test results over the field results. This is the normal trend and is expected. The differences depend on the type of soil, the mixing quality, the compactive effort, the optimum moisture content and the cement content. It appears that the best guide to assessing the performance of soil-cement mix is to determine the in-situ strength with curing age and to decide which curing age after placement comes close to acceptable specification values. In this study, a curing age of 4 to 5 days appear most promising to give adequate strength for construction work to continue. However, in all cases, a trial mix is required to determine the number of passes that will meet the specification requirements.

In-situ moisture content tests could be indirect ways by which strength development could be predicted in a soil-cement mix. It may therefore be desirable to monitor the changes in moisture content with curing age before the seven day period required elapses. The moisture requirements depend on cement content, type of soil and the desired curing age. From field experience it was observed that for the four soil samples tested the moisture content of the processed soil sample affect both the uniformity of mixing and compaction obtained.

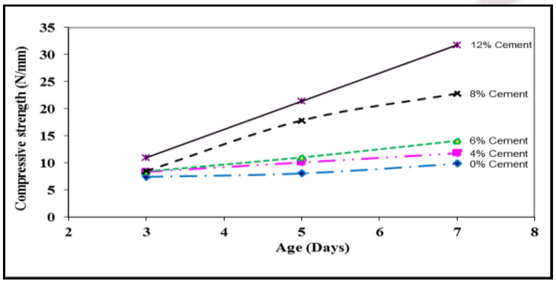

Figure 5: Compressive Strength against Curing Age for TP 1

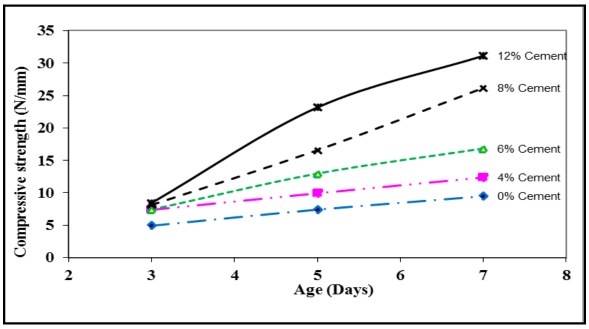

Figure 6: Compressive Strength against Curing Age for TP 2

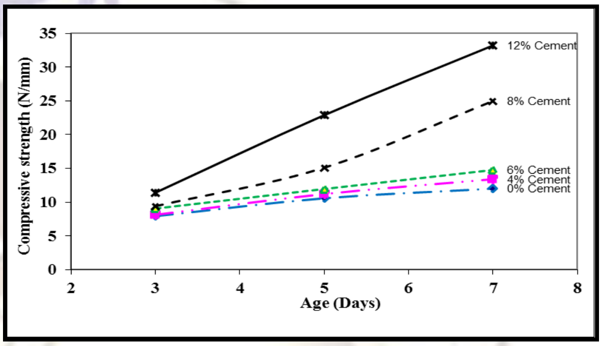

Figure 7: Compressive Strength against Curing Age for TP 3

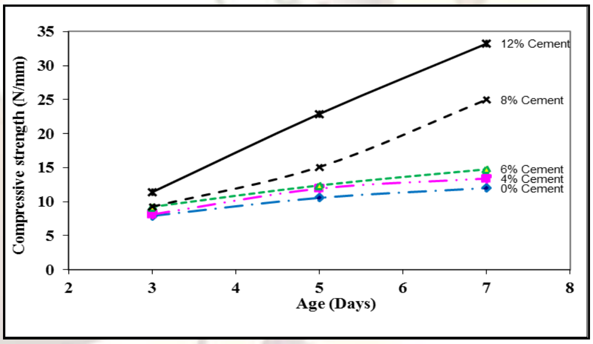

Figure 8: Compressive Strength against Curing Age for TP 4.

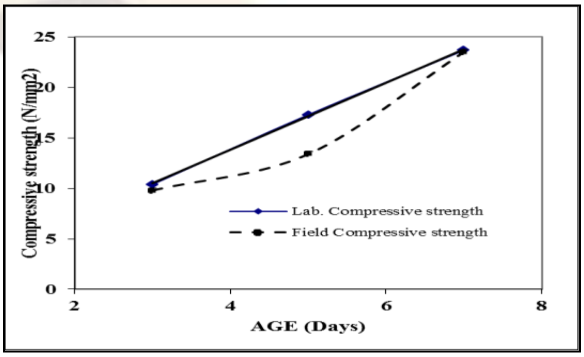

Figure 9: Comparison of Field and Laboratory Compressive Strengths for TP 1

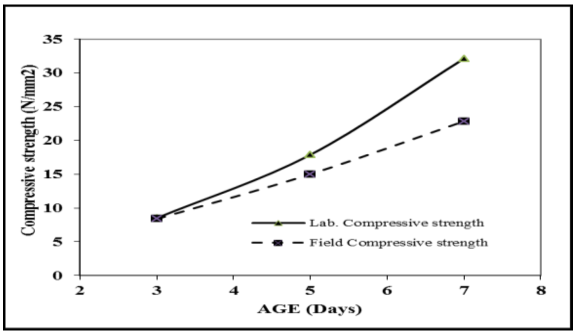

Figure 10: Comparison of Field and Laboratory Compressive Strengths for TP 2

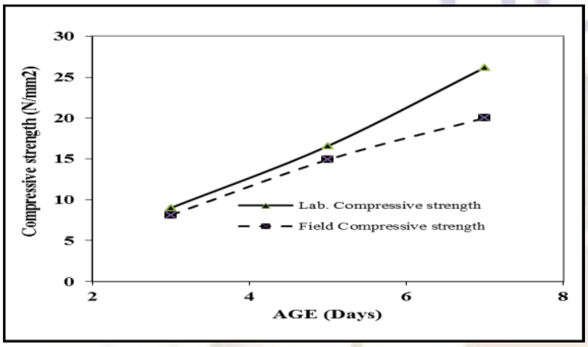

Figure 11: Comparison of Field and Laboratory Compressive Strengths for TP 3.

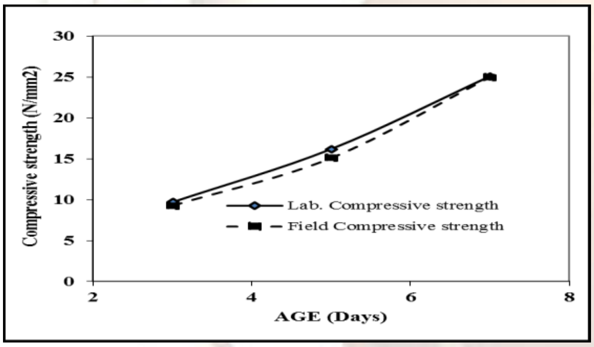

Figure 12: Comparison of Field and Laboratory Compressive Strengths for TP 4

V. CONCLUSION

From the analysis and discussions of the results of this study, the following conclusions can be drawn:

The subgrade conditions on the project site are marginal soils of A-3 to A-4 AASHTO Classification. The A-3 soil being non plastic. The subgrade conditions required cement stablisation to improve its strengths. Thus 4 to 12% cement stablisation was carried out to see which dose of cement would be required to improve the strengths to within specifications requirements. All the cement content (4 to 12%) improved on the strengths at various curing ages.

The 5 day curing age surpassed the minimum specification requirements for road sub-base as follows: 4% cement content at 57% increase in strength, 6% cement content at 74% increase in strength, while 8% and 12% cement content surpasses the maximum by 19.5% and 59% respectively.

Field tests of the soil-cement showed that the strength values were lower than laboratory values for all the trial pits, suggesting that mixing efficiency is higher in the laboratory than in the field. Based on forty-eight number of tests conducted it was observed that the mixing efficiency of not less than 60% of the laboratory values may be required to be applied to the field values in the mix design. The field values could be obtained by prescribing the appropriate number of passes of the compaction equipment.

To get the required design strength prior to the 7 day curing period prescribed in the specification, a cement content of 4%- 6% could be used for minimum specification values and 8% cement content for maximum specification values. However 8% cement content could be used for all cases.

The design strength of 8% cement content was met after 5 days. These are without prejudice to measuring the rates of application, efficiency of pulverization, depth and uniformity of mixing, thickness of compacted layer, density, moisture content, the quality of cement and construction equipment required to execute the work to ensure effective quality control. Normally, an increase of cement content produces a material of better quality. The moisture content of the processed soil affects both the uniformity of mixing and the standard of compaction required. Thus construction work could be allowed to proceed for 2 days prior to the 7-day curing age in specifications

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