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Expansive Soil Improvement with Limestone and Iron Oxide Mixture Case Studies at the Tomata-Beteleme National Road Segment

Edy Sulistianto[1]
Faculty of Engineering
Tadulako University
Jl. Soekarno – Hatta KM 9 Palu

Sukiman Nurdin[2]
Faculty of Engineering
Tadulako University
Jl. Soekarno – Hatta KM 9 Palu

Syamsul Arifin[3]
Faculty of Engineering
Tadulako University
Jl. Soekarno – Hatta KM 9 Palu

Abstract:- Stabilising expansive road subgrade by adding natural limestone and iron oxide is an efficient and economically valuable way of utilising local materials and solving iron oxide waste in environmental problems. In this study, the composition of the mixture was made with proportions: limestone at the optimum level of 6% and iron oxide with varying levels of 0%, 0.2%, 0.4%, 0.8%, and 1.6%. As support in this study, X-ray Diffraction tests and SEM photographs were also conducted to determine the content and composition of expansive clay minerals before and after mixing with stabilisation materials. The test results showed the CBR value without soaking expansive soil compacted according to standard compaction: 12.31%; after being stabilised with 6% limestone and 1.6% iron oxide additive, the value increases to 25.37% with an increased ratio of 106.09%. For the original soil soaking, the CBR value was 8.65%; after stabilisation with 6% limestone and 1.6% iron oxide additive, the value increased to 20.49% with an increase ratio of 136.87%. The results of X-ray Diffraction testing and SEM photos show the addition of new mineral compounds after the original soil is mixed with limestone and iron oxide stabilisation materials, including mineral compounds C-S-H (Calcium Silicate Hydrate). This chemical compound has cementation properties.

Keywords:- *Subgrade, Expansive Soil, Limestone, Iron Oxide.*

I. INTRODUCTION

The subgrade is the lowest layer of pavement construction and is essential because it will carry all construction loads and road traffic. The bearing capacity of the subgrade also determines the thickness and thinness of the pavement foundation layer, thus significantly affecting the cost of road construction or reconstruction. Likewise, in terms of road maintenance, road damage caused by subgrade can cause severe problems that require partial dismantling or complete replacement of road construction on the problematic subgrade, so, understandably, road maintenance costs are expensive.

The road subgrade may be the original ground surface or the filled or excavated ground surface. Road subgrade's physical and technical characteristics vary from place to place of a road section. There have been many cases of damage and failure of road construction caused by problems in the subgrade where the bearing capacity and stability to traffic loads are vulnerable to the influence of environmental conditions; one type of problematic soil is expansive soil, this is evidenced by the many studies conducted in finding solutions to these problems.

The phenomenon of expansive soil problems is widely experienced in various countries in the world in terms of construction and causes significant material losses (Chen, 1975). Expansive soils have also been found in Indonesia. The most prominent characteristic of expansive soils is the ability to shrink when experiencing changes in moisture content. In wet conditions, the soil volume will increase (expand) and in dry conditions, the soil volume will shrink. This large range of volume changes is what often causes damage to road construction and other building construction.

Expansive soil contracts due to clay minerals and structures that allow water to enter the layer. A high plasticity index characterises this or can visually be seen on the surface of the soil cracking in the dry season.

Stabilisation or improvement of physical and technical properties is one method that can be applied by adding cheap stabilisation materials and utilising local materials found around the location. This study used two stabilisation materials: expansive soil stabilisation with limestone and limestone plus iron oxide additives. Research on the use of lime materials for stabilising subgrade soils has now been widely carried out and proven effective in improving the technical properties of expansive soils; besides that, lime

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materials are easily obtained and relatively cheap. The iron oxide used in this research is iron (III) oxide (Fe2O3), resulting from recycling iron powder waste produced by metal industry lathes and hoarding scrap iron goods that are no longer used. Iron rust is a chemical compound with the formula iron(III) oxide. Indonesia has a lot of iron powder waste and scrap iron, especially in industrial areas. If it can be utilised, it is an added economic value and a solution to environmental problems.

On the national road of Central Sulawesi Province, to be precise, the 50.94 km Tomata-Beteleme road section located in the North Morowali district is an arterial road connecting Central Sulawesi province and Southeast Sulawesi province, most of which in this section often experiences quite severe damage. From the results of field observations, the most visible damage is the corrugated surface layer pavement and the occurrence of cracks (rutting) and, in some places, landslides on the edge of the road body. The topography of this road section is hilly, and a small part is plain. Until now, the government, in this case, the Ministry of Public Works and Public Housing through the Directorate General of Highways, has made efforts to deal with damage in various ways, including road reconstruction by installing geomembranes and installing mini piles in areas that are often damaged and prone to landslides. Based on the type of damage in this road section indicates that the road base soil is expansive; to support this, it is necessary to conduct laboratory research and testing.

II. RESEARCH METHOD

Expansive soil samples used in this study were taken from the Tomata-Beteleme national road section, precisely at the location experiencing severe damage.

- *Flow Chart of Research*

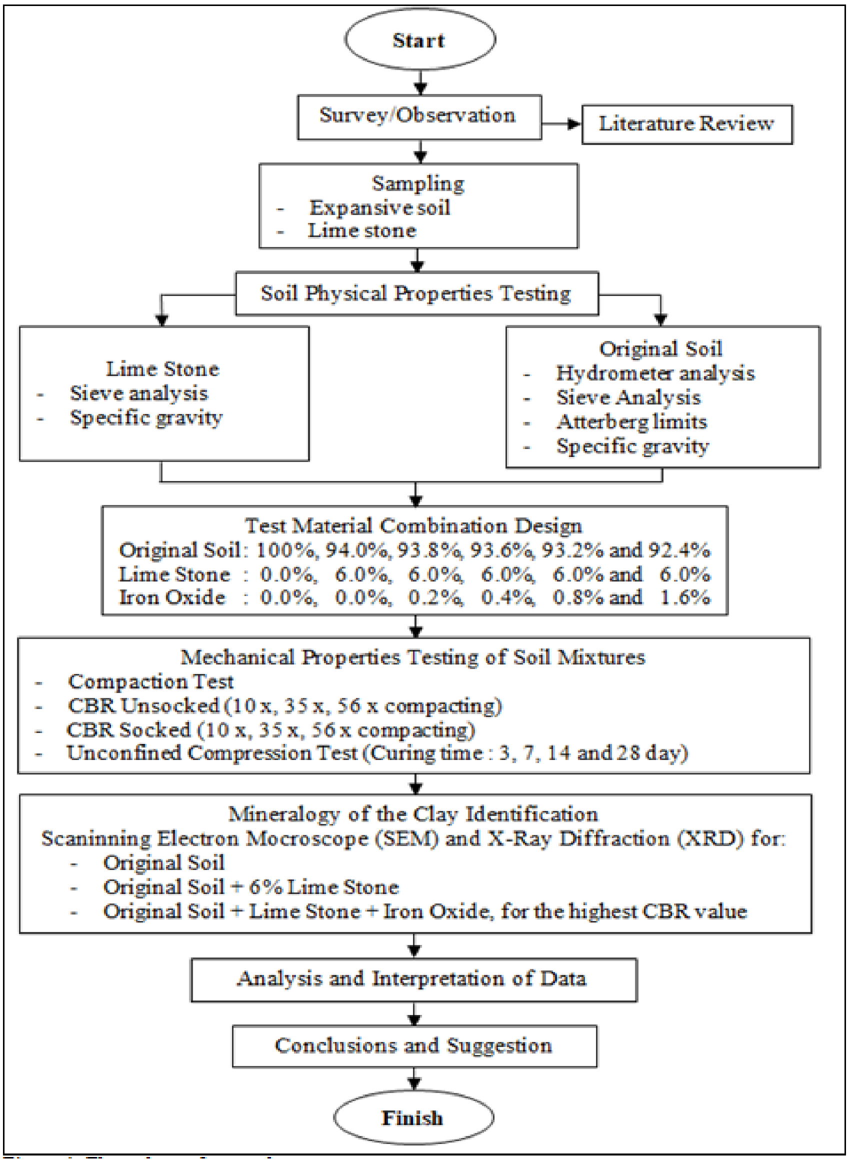

Fig 1 Flow Chart of Research

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Laboratory testing is carried out in two phases, namely, examination of the physical and mechanical properties of the soil. The study of physical properties for purposes in grouping soil types or classifications is tested as follows;

➢ *Original Soil*

- Grain Size Analysis and Hydrometer
- Specific gravity (Gs)
- Atterberg limits

➢ *Limestone*

- Grain Size Analysis and Hydrometer
- Specific gravity (Gs)

Examination of mechanical properties of the effectiveness of stabilisers in soil stability and bearing capacity is carried out as follows;

- Compaction Test
- CBR Unsocked
- CBR Socked
- Unconfined Compression

In the test of the mechanical properties of the original soil and the stabilised original soil, the design of the mixture was carried out as follows;

- Lime stone at the optimum content of 6%
- Iron oxide with content varying from 0.20%, 0.40%, 0.80% and 1.60%

In addition to mechanical properties testing, SEM and XRD tests were also carried out to determine changes in the structure and mineral compounds in the stabilised soil.

III. RESULT

A. *Physical Properties of Soil*

Testing of soil physical properties of soil samples taken on the Tomata-Beteleme National Road km. 356+200 can be seen as follows;

Table 1 Recapitulation of Soil Sample Properties Test Results Data

No.	Properties Index Testing		Subgrade of Tomata-Beteleme National Road section
1	Grain Size Analysis :	Passed No. 4 (%)	100,00
		Passed No. 40 (%)	88,36
		Passed No. 200 (%)	40,96
		Passed < 0.002 mm (%)	6,93
2	Atterberg limits :	Liquid Limit (LL) (%)	43,82
		Plastic Limit (PL) (%)	28,54
		Plasticity Index (PI) (%)	15,28
3	Specific gravity (Gs)		2,672
4	Activity (Ac) = PI / CF(% Clay)		2,20
5	Soil Classification :	Unified System (USCS)	SM
		AASHTO System	A-7-6

Table 2 Lime Stone Properties Test Result Data

No.	Properties Index Testing		Lime Stone Taliwan Village, North Morowali
1	Grain Size Analysis :	Passed No. 4 (%)	47,32
		Passed No. 40 (%)	19,91
		Passed No. 200 (%)	5,370
2	Specific gravity (Gs)		2,387
3	Soil Classification :	Unified System (USCS)	SP
		AASHTO System	A-1-a

- *Grain Size Analysis and Hydrometer*

The following curve graphs show the results of sieve analysis and hydrometer testing of the original soil and limestone.

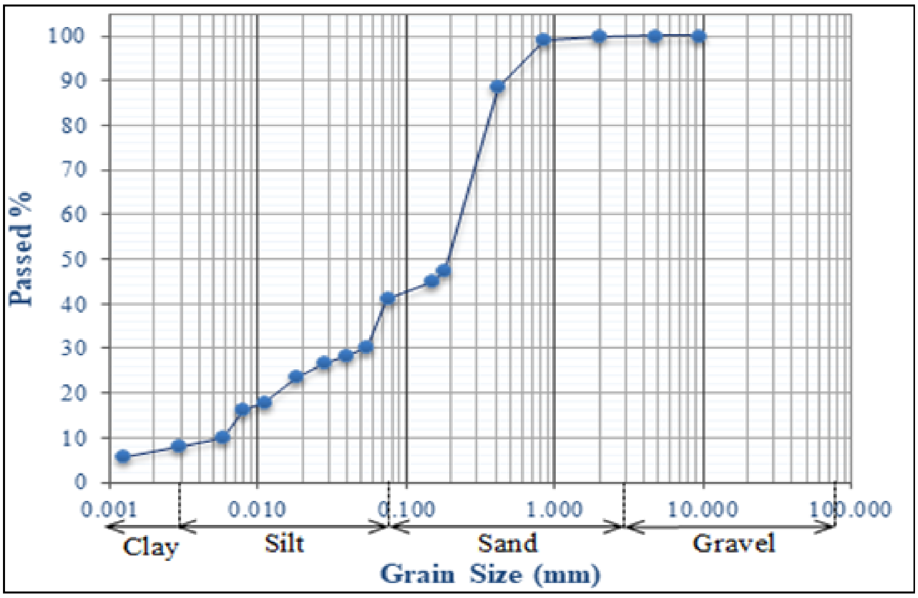

Fig 2 Grain Size Distribution Curve of Original Soil

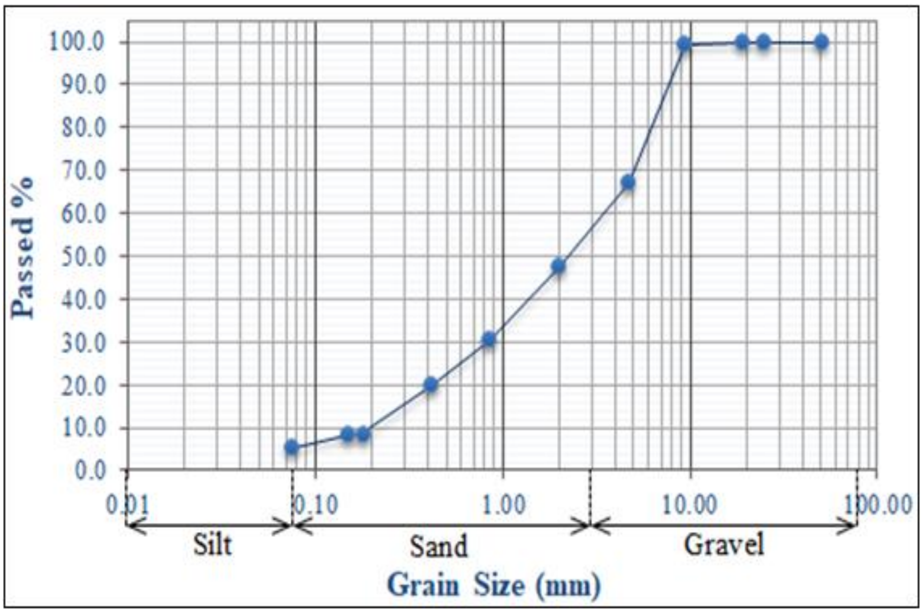

Fig 3 Limestone Grain Size Distribution Curve

- *Specific Gravity (Gs)*

The specific gravity test results of the original soil and limestone are as follows:

Table 3 Specific Gravity Test

No.	Specific Gravity Test	Subgrade of Tomata-Beteleme National Road Section
1	The specific gravity of original soil	2.672
2	The specific gravity of Lime Stone	2.387

- *Atterberg Limits*

The Atterberg limits test results of the original soil are shown below:

Table 4 Atterberg Limits Test

LL	PL	PI = LL - PL
43,82	28,54	15,28

B. *Mechanical Properties of Soil*

Testing of soil mechanical properties here is carried out to analyse the effect of stabilisers on improving the performance of the original soil in its function as a road subgrade construction.

➢ *Compaction Test*

Table 5 Compaction Test

No.	Mixture Variation			W Opt.	γdry
	Original soil	**Lime Stone**	**Iron Oxide**	**(%)**	**(gram/cm³)**
1	100%	0%	0%	16,04	1,412
2	94,0%	6,0%	0%	12,07	1,786
3	93,8%	6,0%	0,2%	10,44	1,881
4	93,6%	6,0%	0,4%	9,48	1,886
5	93,2%	6,0%	0,8%	9,40	1,892
6	92,4%	6,0%	1,6%	7,61	1,934

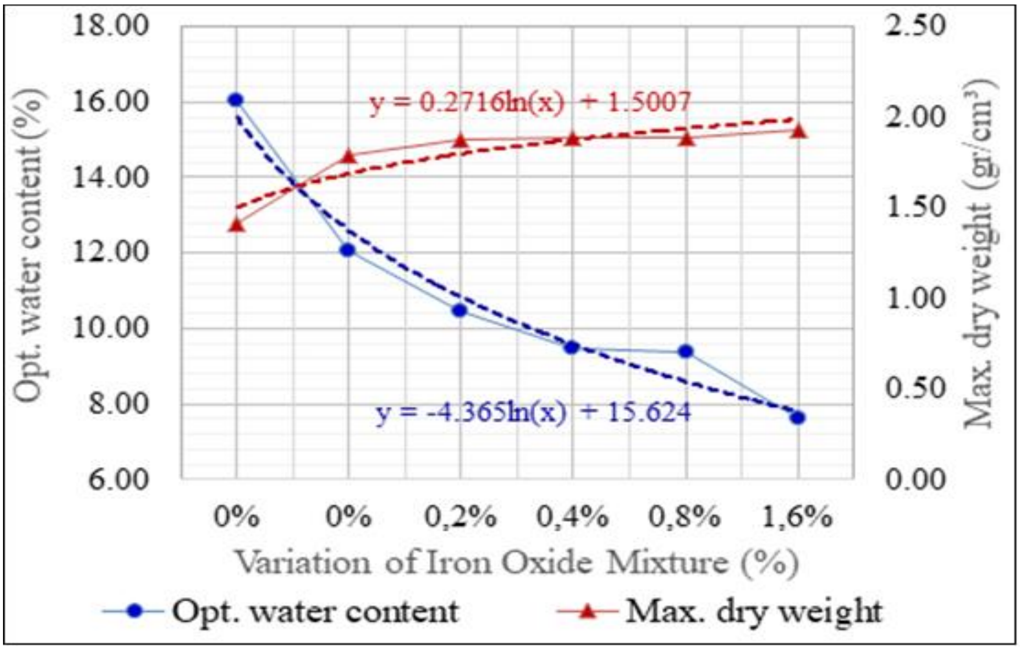

Fig 4 The Relationship between Wopt. and γdry with Iron Oxide Variations

The test results showed an increase in the dry weight of the soil along with an increase in iron oxide content. The decrease in optimum moisture content is directly proportional to the bearing capacity of the soil as a road subgrade.

➢ *Unconfined Compression Test*

The free compressive strength (Qu) value is the maximum compressive strength (at collapse) of the loaded sample (without restraint σ3). For saturated clays (Ø = 0), the free compressive strength Qu = 2 Cu. Modulus of Elasticity is a constant between stress and strain; this value indicates the limit of the soil's ability to maintain its original shape when the load is removed.

The free compressive strength test was carried out on 21 test samples with a mixture composition: original soil + 6% limestone + iron oxide variations of 0.2%, 0.4%, 0.8% and 1.6% with curing times of 3, 7, 14 and 28 days. The test results are presented in the following graphic form. The elastic modulus value is obtained using the Secant modulus method from the free compressive strength graph.

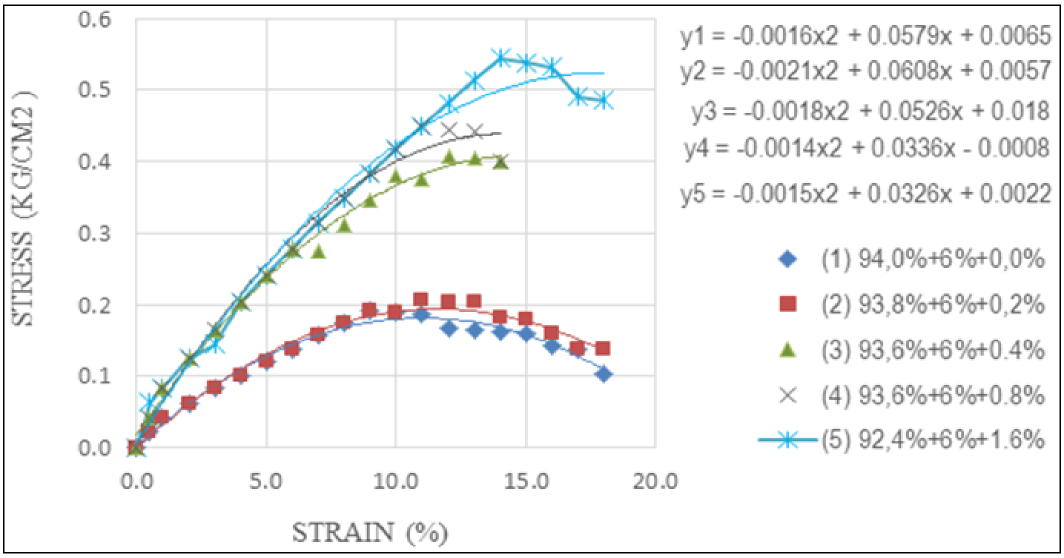

Fig 5 Stress and Strain Diagram for Three Days of Curing Time

Table 6 Values of Stress and Modulus of Elasticity for Three Days of Curing Time

No.	Mixed Combination Variations	Stress (Qu)	Secant Modulus
		kg/cm²	MPa
1.	Original Soil + Lime Stone 6% + Iron Oxide 0,0%	0.182	0.276
2.	Original Soil + Lime Stone 6% + Iron Oxide 0,2%	0.199	0.280
3.	Original Soil + Lime Stone 6% + Iron Oxide 0,4%	0.396	0.461
4.	Original Soil + Lime Stone 6% + Iron Oxide 0,8%	0.442	0.516
5.	Original Soil + Lime Stone 6% + Iron Oxide 1,6%	0.519	0.491

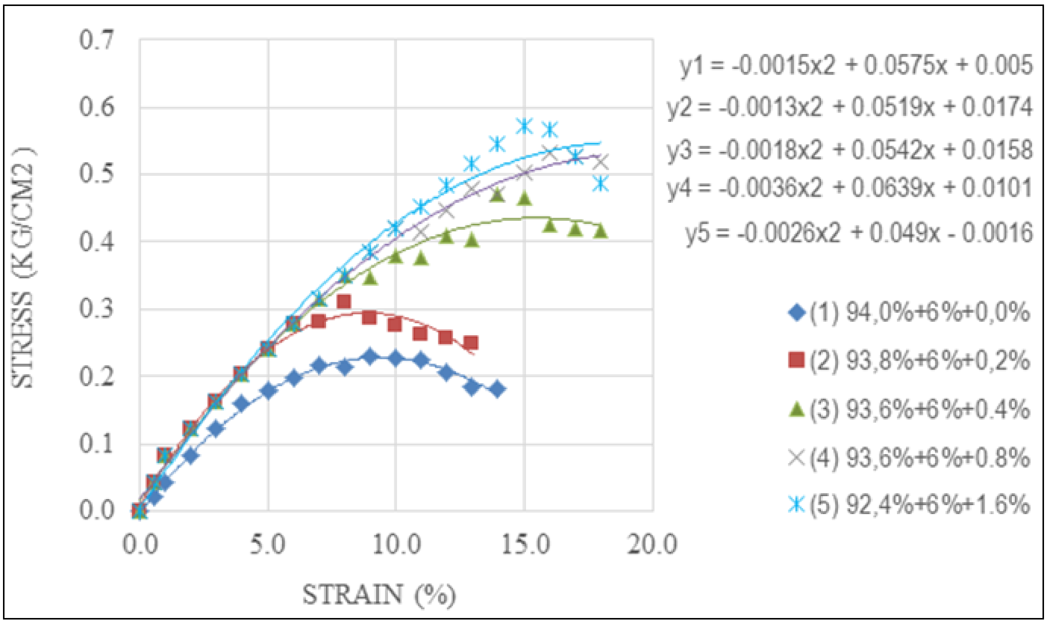

Fig 6 Stress and Strain Diagram for 7 Days Curing Time

Table 7 Stress Values and Modulus of Elasticity for 7 Days of Curing Time

No.	Mixed Combination Variations	Stress (Qu)	Secant Modulus
		kg/cm²	MPa
1.	Original Soil + Lime Stone 6% + Iron Oxide 0,0%	0.227	0.407
2.	Original Soil + Lime Stone 6% + Iron Oxide 0,2%	0.292	0.583
3.	Original Soil + Lime Stone 6% + Iron Oxide 0,4%	0.438	0.455
4.	Original Soil + Lime Stone 6% + Iron Oxide 0,8%	0.517	0.462
5.	Original Soil + Lime Stone 6% + Iron Oxide 1,6%	0.537	0.486

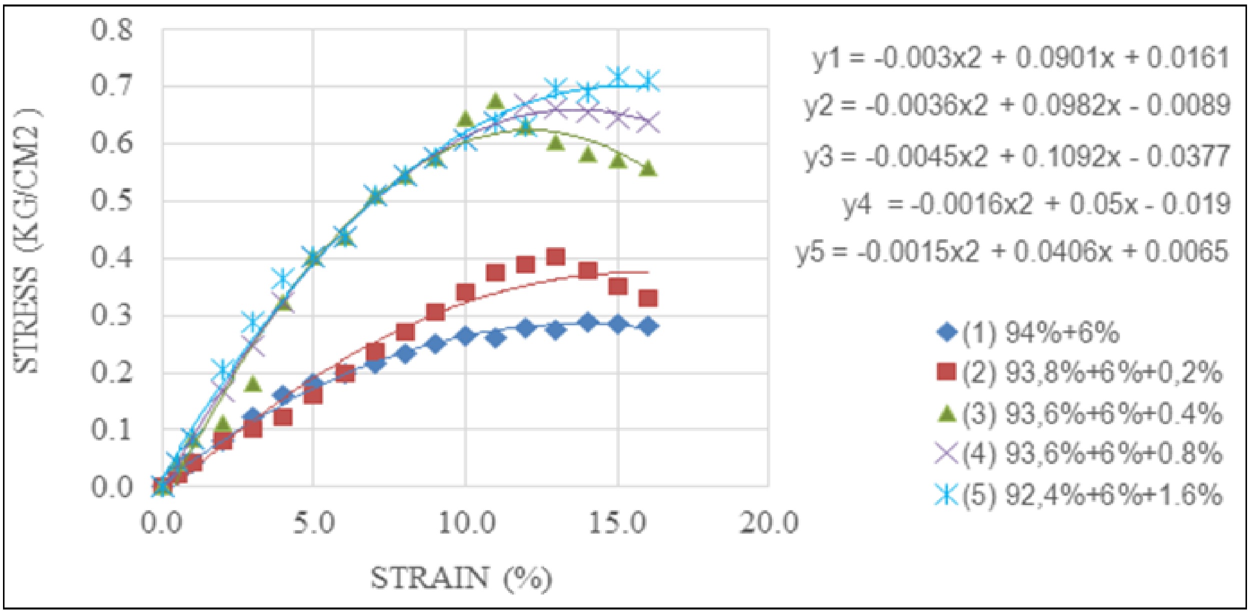

Fig 7 Stress and Strain Diagram for 14 Days of Curing Time

Table 8 Stress Values and Modulus of Elasticity for 14 Days of Curing Time

No.	Mixed Combination Variations	Stress (Qu)	Secant Modulus
		kg/cm²	MPa
1.	Original Soil + Lime Stone 6% + Iron Oxide 0,0%	0.278	0.348
2.	Original Soil + Lime Stone 6% + Iron Oxide 0,2%	0.405	0.387
3.	Original Soil + Lime Stone 6% + Iron Oxide 0,4%	0.600	0.888
4.	Original Soil + Lime Stone 6% + Iron Oxide 0,8%	0.658	0.804
5.	Original Soil + Lime Stone 6% + Iron Oxide 1,6%	0.719	0.746

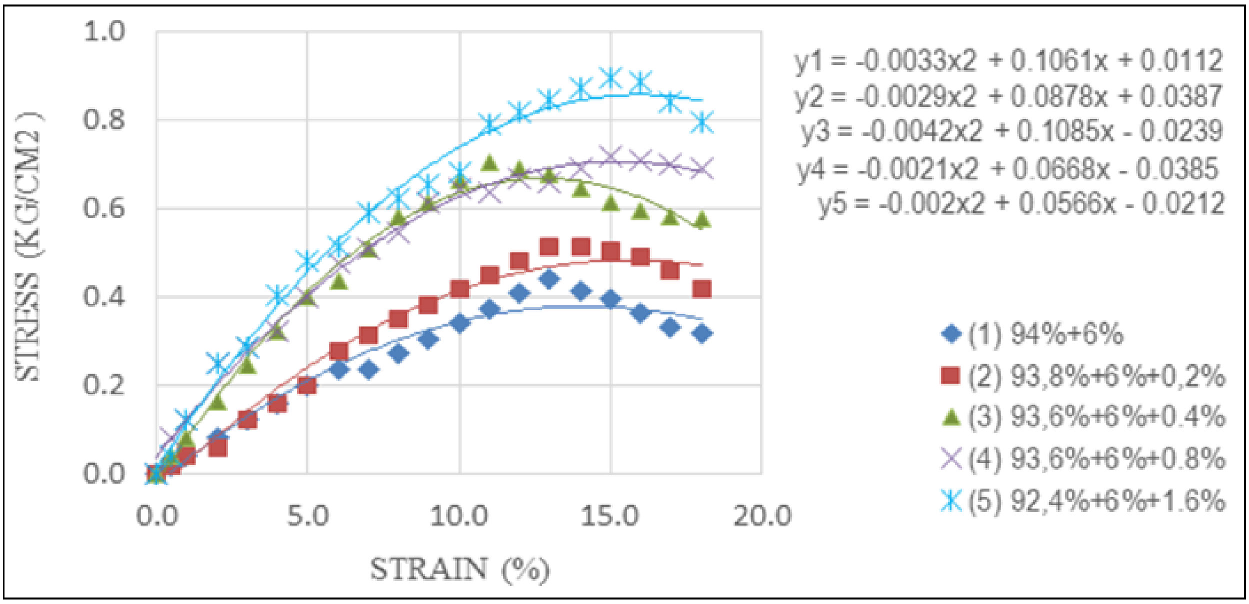

Fig 8 Stress and Strain Diagram for 28 Days Curing Time

Table 9 Values of Stress and Modulus of Elasticity for 28 Days of Curing Time

No.	Mixed Combination Variations	Stress (Qu)	Secant Modulus
		kg/cm²	MPa
1.	Original Soil + Lime Stone 6% + Iron Oxide 0,0%	0.494	0.381
2.	Original Soil + Lime Stone 6% + Iron Oxide 0,2%	0.596	0.458
3.	Original Soil + Lime Stone 6% + Iron Oxide 0,4%	0.660	0.895
4.	Original Soil + Lime Stone 6% + Iron Oxide 0,8%	0.703	0.778
5.	Original Soil + Lime Stone 6% + Iron Oxide 1,6%	0.866	0.900

Table 10 Relationship between Qu Values and Variations of Iron Oxide with Curing Time

No.	Mixed Variations			Curing Time (Days)			
	Original Soil	Lime Stone	Iron Oxide	3	7	14	28
					Qu (kg/cm²)		
1.	94,0%	6.0%	0.0%	0.182	0.227	0.278	0.494
2.	93,8%	6.0%	0.2%	0.199	0.292	0.405	0.596
3.	93,6%	6.0%	0.4%	0.396	0.438	0.600	0.660
4.	93,2%	6.0%	0.8%	0.442	0.517	0.658	0.703
5.	92,4%	6.0%	1.6%	0.519	0.537	0.719	0.866

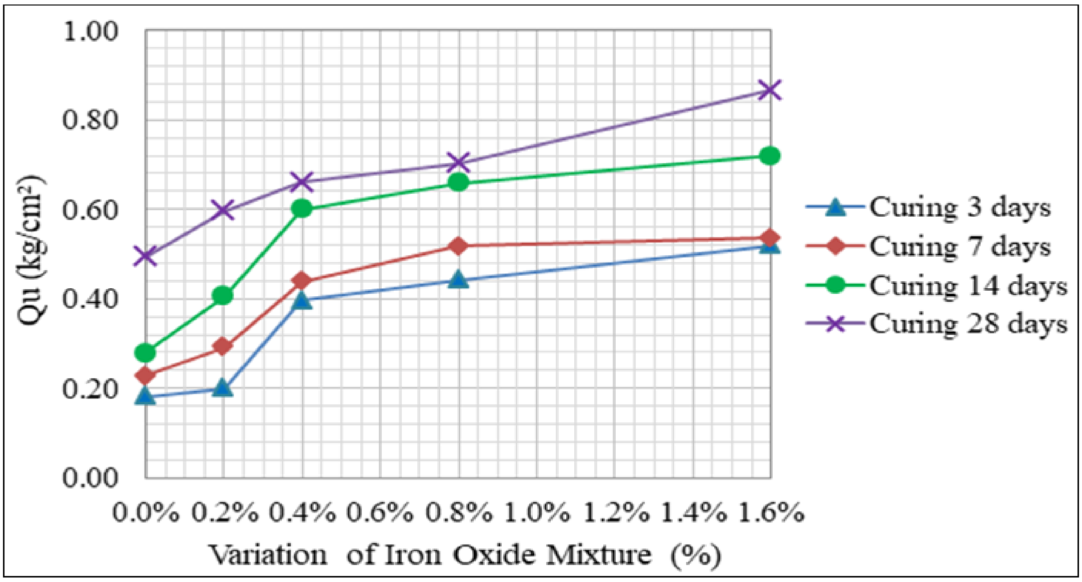

Fig 9 Graph of the Relationship between Qu Values and Variations of Iron Oxide Mixtures

➢ *California Bearing Ratio (CBR) Laboratory*

This test determines the CBR value of subgrade, subbase and foundation materials, including recycled materials for road pavements and airport runways. The CBR value indicates the density and carrying capacity of the soil or mixture of soil materials in its maximum solid state.

In this test, 16 test samples were used, namely original soil with 1 sample, original soil + 6% limestone with 3 samples and original soil + 6% limestone + iron oxide with varied mixture levels of 0.2%, 0.4%, 0.8% and 1.6% with 3 samples each. For compaction of the original soil, one variation is carried out with a total of 56x compaction, while mixed soil is carried out in three compaction levels, namely 10x, 35x and 56x.

- *CBR Unsoaked*

Table 11 Unsoaked CBR Test Results

No. Sample	Mixture			Unsoaked CBR Value (%)		
	Original soil	Lime Stone	Iron Oxide	Compaction (x) Variation		
	(%)	(%)	(%)	10	35	56
1.	100,00	0,00	0,00	-	-	12,305
2.	94,00	6,00	0,00	10,714	13,910	15,601
3.	93,80	6,00	0,20	11,654	15,413	16,729
4.	93,60	6,00	0,40	12,594	16,353	17,481
5.	93,20	6,00	0,80	13,910	17,669	19,737
6.	92,40	6,00	1,60	17,481	23,872	25,376

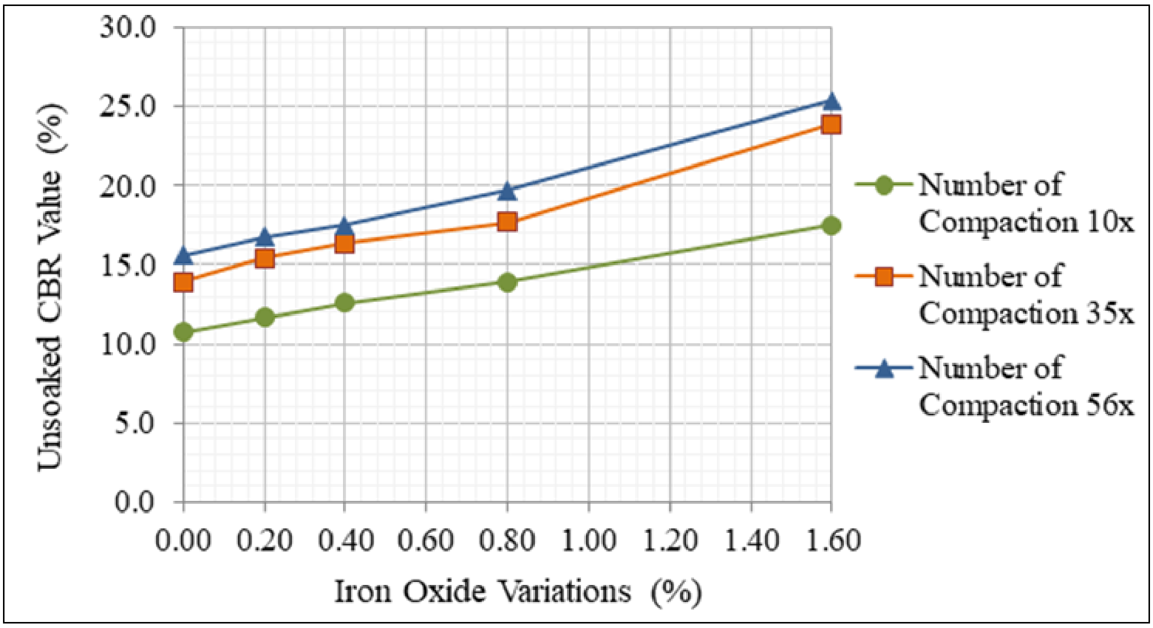

Fig 10 Graph of the Relationship between unsoaked CBR value and iron oxide variation

The test results for 15 mixed soil test samples showed an increase in the value of CBR (Unsoaked) with increasing levels of iron oxide in the three variations of compaction. The highest CBR values are 17.48%, 23.87% and 25.38%.

- *CBR Soaked*

Table 12 Soaked CBR Test Results

No. Sample	Mixture			Soaked CBR Value (%)		
	Original soil	Lime Stone	Iron Oxide	Compaction (x) Variation		
	(%)	(%)	(%)	10	35	56
1.	100,00	0,00	0,00	-	-	8,65
2.	94,00	6,00	0,00	6,58	8,08	10,71
3.	93,80	6,00	0,20	7,52	9,77	12,41
4.	93,60	6,00	0,40	8,08	10,71	15,04
5.	93,20	6,00	0,80	10,34	13,16	18,42
6.	92,40	6,00	1,60	13,35	16,17	20,49

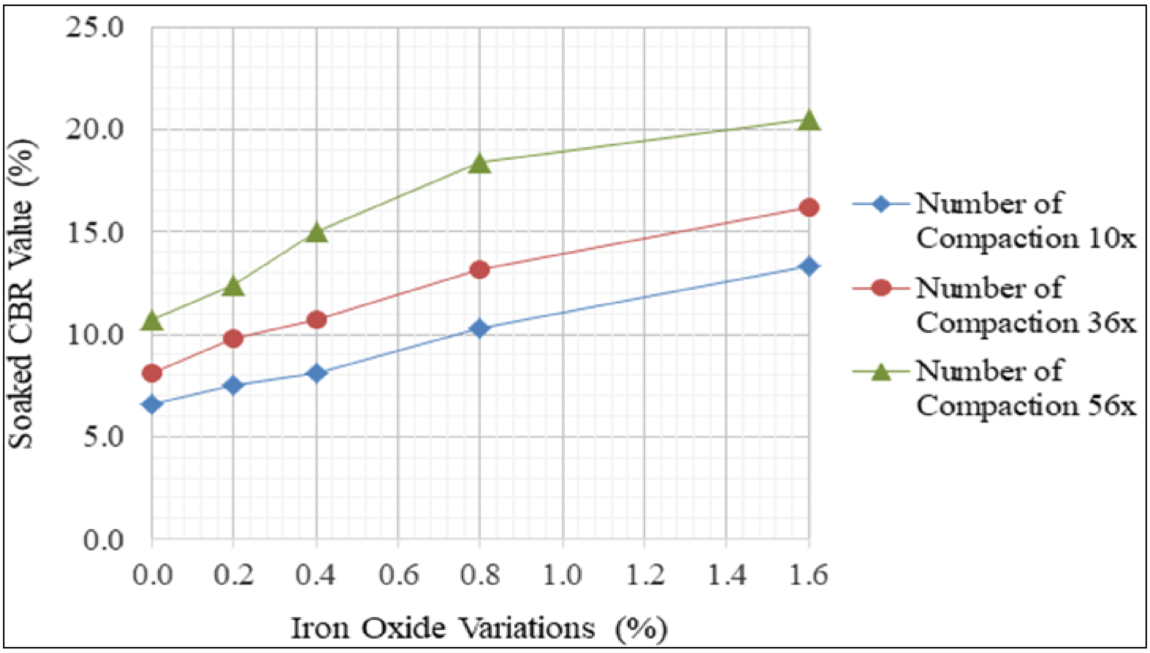

Fig 11 Relationship between Soaking CBR Value and Iron Oxide Variation

The test results of the highest CBR (Soaked) value for 15 mixed soil test samples with compaction variations of 10x, 35x and 56x are sequential: 13.35%, 16.17% and 20.49%.

C. SEM (Scanning Electron Microscope) Testing

SEM (Scanning Electron Microscope) testing was carried out on original soil samples, original soil + 6% limestone and original soil + 6% limestone + 1.6% iron oxide, to obtain topography and surface morphology data of the samples through SEM photos with magnification scale 1×10^5 to 1×10^6.

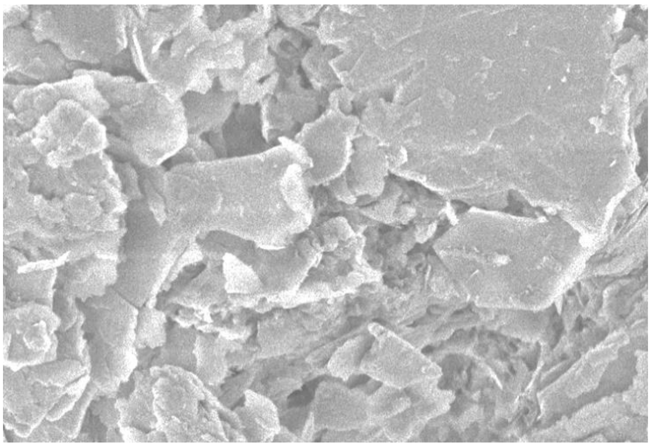

Fig 12 Original Soil Structure, Object Magnification Scale (1×10^5) Times

The bright colour image seen in the sample is soil minerals in the crystalline phase, where one of the properties of the crystal will reflect light when exposed to light, while the dim colour shows soil minerals in the amorphous phase.

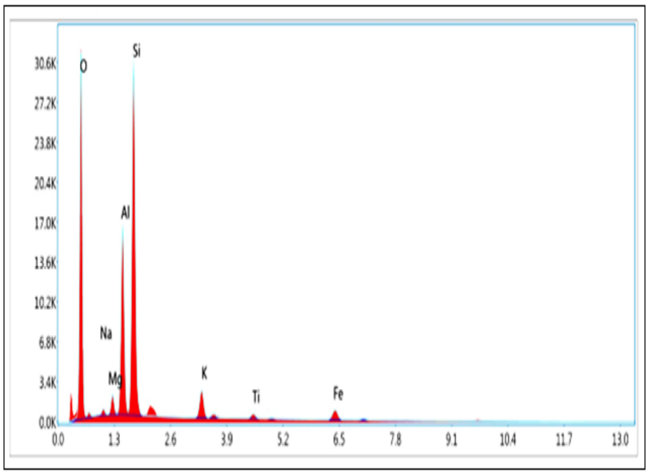

Fig 13 EDX Spectrum Test, Original Soil Sample

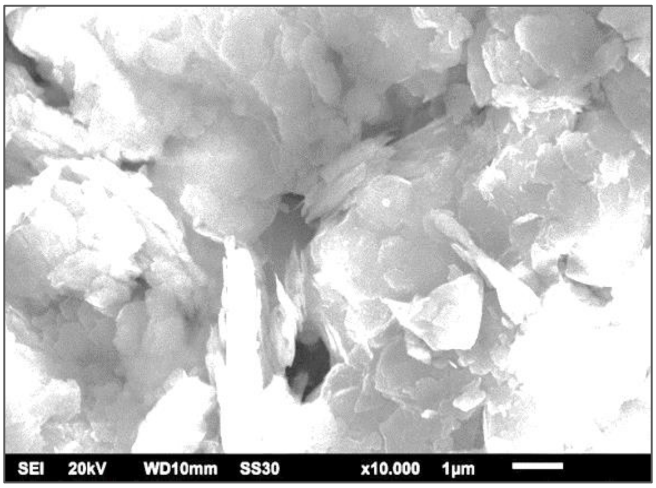

Fig 14 Original Soil Structure + Lime Stone 6% Object Scale (1×10^6) Times

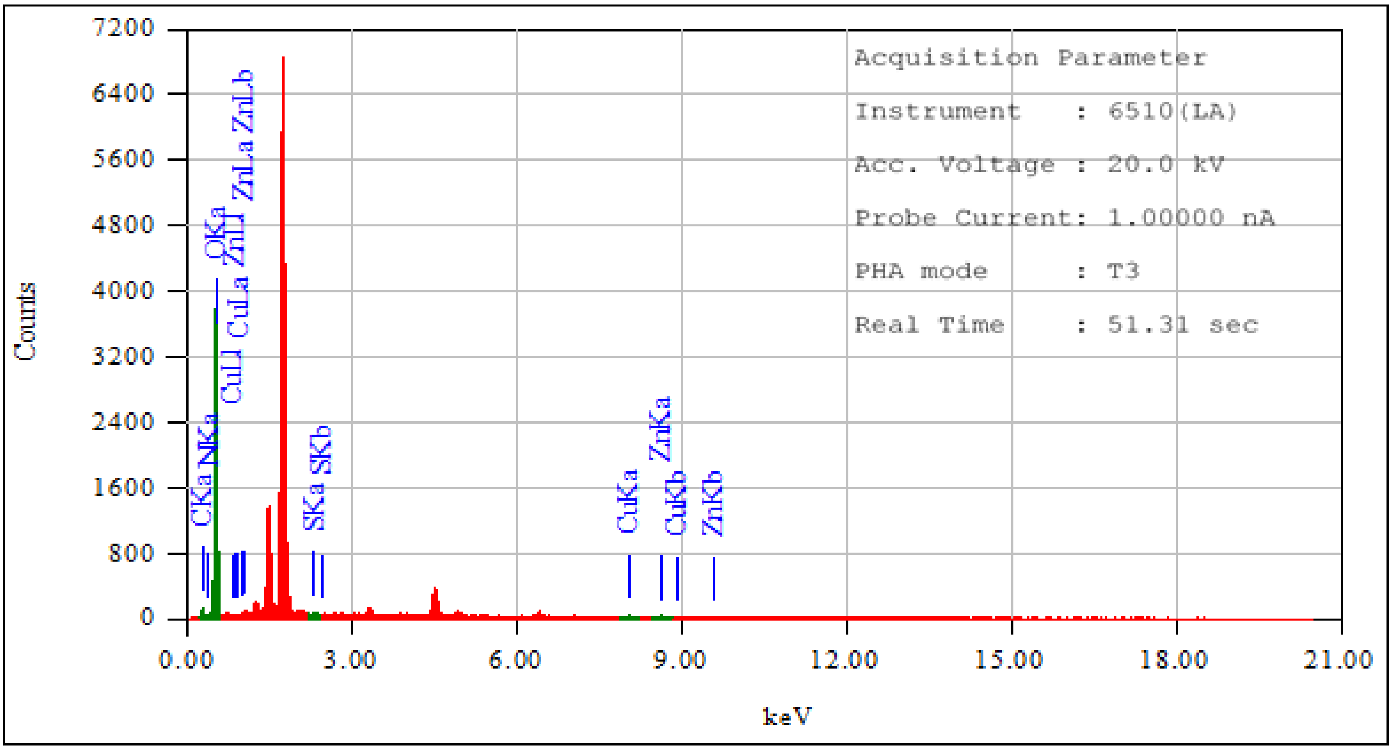

Fig 15 EDX Spectrum Test, Original Soil + 6% Limestone

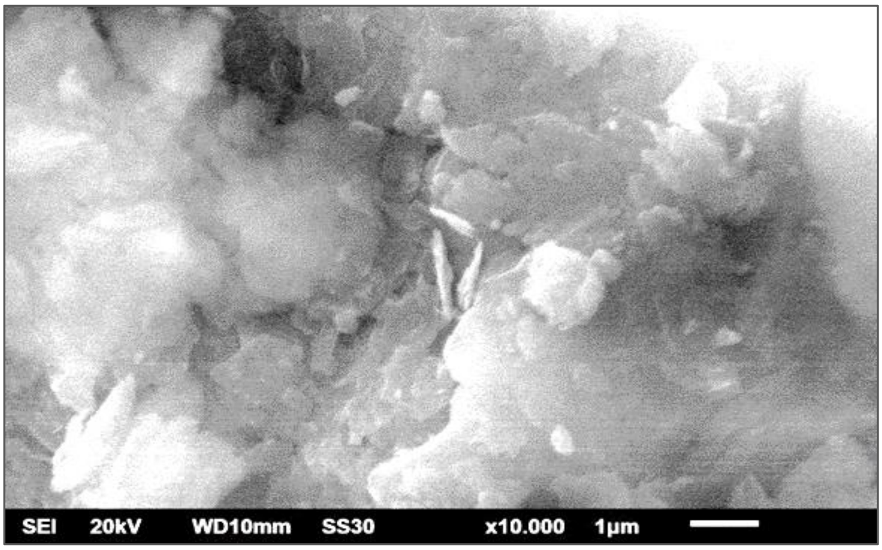

Fig 16 Original Soil Structure + Limestone 6% + Iron Oxide 1.6% Object Scale (1x10[6]) Times

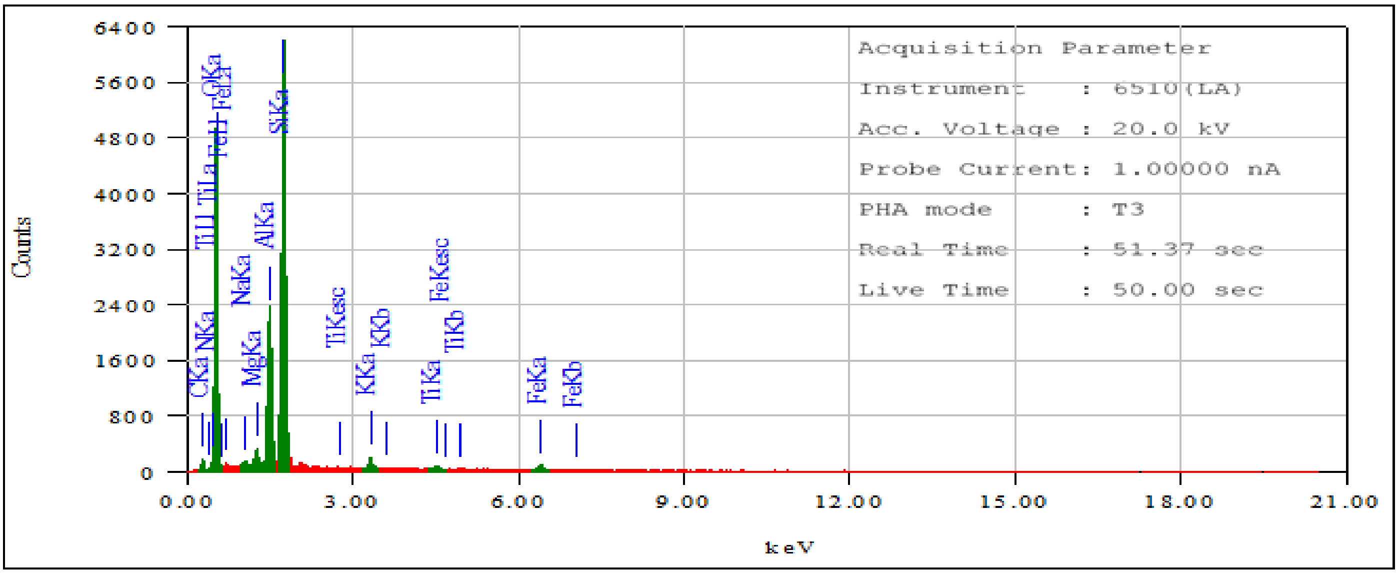

Fig 17 EDX Spectrum Test, Original Soil + 6% Limestone + 1.6% Iron Oxide

From the SEM test results above with magnification up to 1.0 μm, it can be seen that the addition of limestone stabilizers and iron oxide additives has reduced the voids in the arrangement of soil particles; this shows that the addition of stabilisers makes the structure of soil particles tighter.

D. XRD (X-ray Diffraction) Test Results

XRD method is an analytical technique used to identify the phase of crystalline material samples or solid material in powder form. From the XRD test results, the composition of the clay mineral content in the crystalline phase and the rest in the amorphous phase is obtained; the test results are then displayed in the following table.

Table 13 Identified Mineral Content of Original Soil Samples

No.	Phase/Mineral	Formula	Crystal	Density	Content
1	Quartz	O_2Si	trigonal	2.80 g/cm³	78.20%
2	Amarillite	$FeH_{12}NaO_{14}S_2$	monoclinic	2.22 g/cm³	7.20%
3	Illite	$Al_2H_2KO_{12}Si_4$	monoclinic	2.82 g/cm³	6.90%
4	Albite	$AlNaO_8Si_3$	triclinic	2.98 g/cm³	5.90%
5	Montmorillonite	$Al_{0.86}Cs_{0.08}Fe_{0.1}HMg_{0.14}O_{10}Si_{3.9}$	monoclinic	2.01 g/cm³	1.80%

Table 14 Identified Mineral Content of Original Soil Samples + Limestone 6%

No.	Phase/Mineral	Formula	Crystal	Density	Content
1	Quartz	O_2Si	trigonal (hexagonal)	2.77 g/cm³	85.50%
2	Albite	$AlNaO_8Si_3$	cubic	2.98 g/cm³	5.90%
3	Illite	$Al_2H_2KO_{12}Si_4$	trigonal (hexagonal)	2.83 g/cm³	4.60%

4	Trimg. Cal. Carbonate	$C_4CaMg_3O_{12}$	trigonal (rhombohedral)	2.87 g/cm³	1.90%
5	Calcium Carbonate	$CCaO_3$	monoclinic	2.71 g/cm³	1.40%
6	Calcium oxide/Lime	CaO	triclinic (anorthic)	3.41 g/cm³	0.70%

Table 15 Identified Minerals of Original Soil Sample + Lime Stone 6% + Iron Oxide 1.6%

No.	Phase/Mineral	Formula	Crystal	Density	Content
1	Quartz	O_2Si	trigonal (hexagonal axes)	2.802 g/cm³	76.10%
4	Afwillite	$Ca_3H_6O_{10}Si_2$	triclinic (anorthic)	2.628 g/cm³	7.40%
2	Clinotobermorite	$Ca_5H_8O_{21}Si_6$	triclinic (anorthic)	2.530 g/cm³	5.20%
3	Tobermorite	$Ca_{2.25}H_7O_{11}Si_3$	monoclinic	2.522 g/cm³	4.30%
6	Portlandite	CaH_2O_2	trigonal (hexagonal axes)	2.586 g/cm³	3.10%
5	Periclase	MgO	Cubic	3.296 g/cm³	3.00%
7	iron oxide	Fe_3O_4	Cubic	5.224 g/cm³	0.90%

The results of this XRD test show the formation of new mineral compounds, including Clinotobermorite (Ca5H8O21Si6), Tobermorite (CaH2O2) and Portlandite (CaH2O2). These are C-S-H compounds that are cementation and this is similar to the content of the C3S compound of Portland cement, namely silicate (Si), aluminate (Al) and calcium (CaO) compounds.

IV. CONCLUSION

Based on the results of testing and analysis of road base soil samples of the Tomata-Beteleme national road section, stabilisers, namely limestone and iron oxide additives, significantly improve the physical and mechanical properties of the stabilised native soil, with the following detailed results:

- Testing the value of stability (CBR) expansive subgrade compacted according to standard compaction obtained CBR value unsoaked for the original soil 12.31% after stabilised with limestone content of 6% and additive iron oxide 1.6% value increased to 25.37% with an increase ratio of 106.09%. For the original soil-soaked CBR of 8.65%, after being stabilised with 6% limestone and 1.6% iron oxide additives, the value increased by 20.49% with an increased ratio of 136.87%.
- The X-ray Diffraction and SEM test results of mixing the stabilisation material with the original soil showed the addition of new chemical compounds, namely the mineral compound C-S-H (Calcium Silicate Hydrate), which has cementation properties.

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