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Laboratory Study on the Impact of Ferrochrome Slag and Zycobond for Stabilization of Marine Clay Subgrade

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Abstract: India, with a coastline stretching over 7,516 kilometers, relies heavily on its coastal infrastructure to support import and export activities that are vital to the nation's economic growth.The subsoil in many of these regions predominantly consists of marine clay, which is highly compressible, weak in shear strength, and highly susceptible to moisture variations making it unsuitable for pavement subgrades.These unfavourable characteristics compromise the stability and load-bearing capacity of foundations and infrastructure built on such soils.This study investigates the effectiveness of ferrochrome slag, an industrial by-product, and Zycobond, a chemical soil stabilizer, in enhancing the properties of marine clay.Experimental results reveal that the addition of FCS and Zycobond significantly enhances the strength and stability of the clay.The optimum blend resulted in a substantial increase in CBR value, making the treated marine clay suitable for pavement subgrade layers.The study concludes that the combined use of ferrochrome slag and Zycobond provides a cost-effective and sustainable solution for stabilizing weak soils.
Keywords: Marine Clay, Ferrochrome slag, Zycobond, CBR, Subgrade.

I. INTRODUCTION

India, with its long coastline and strategic maritime location, has witnessed rapid industrial and infrastructural growth.Over the centuries, these maritime connections have evolved from simple trade routes to major economic corridors, facilitating globalization and industrial growth.one of the major challenges faced along the Indian coastline is the presence of weak and compressible soils.These soft marine and coastal deposits often lack the strength and stability required to support heavy loads.Marine clay generally exhibits low bearing capacity, high plasticity, and excessive settlement under load, making it unsuitable for direct construction of heavy structures such as roads, ports, and industrial facilities.When large infrastructures such as ports, roads, and buildings are constructed on such soils without proper ground improvement, they may experience settlement or even structural failure.

Additionally, marine clays exhibit high sensitivity to stress variations, which makes them particularly problematic when used as pavement subgrades.Such soils possess high compressibility, low shear strength, poor drainage characteristics, and very low bearing capacity. As a result, pavements constructed on untreated marine clay often experience excessive deformation, settlement, and premature failure.Therefore, stabilization of marine clay becomes essential to improve its strength and performance as a suitable pavement subgrade material.

Stabilization techniques are essential to improve the engineering behaviour of marine clays, especially when they are used as pavement subgrades.The main objective is to enhance the strength, durability, and load-bearing capacity of the soil while reducing its compressibility, permeability, and plasticity.It provides a sustainable and cost-effective solution to improve soil performance, ensuring the long-term stability and serviceability of structures such as pavements, foundations, and embankments.

II. OBJECTIVES OF THE STUDY

The Objectives of the present Laboratory study are:

1) To evaluate the geotechnical properties of untreated marine clay.
2) To investigate the effect of ferrochrome slag as an additive for stabilization of marine clay.
3) To assess the influence of Zycobond as a chemical binder in combination with ferrochrome slag.

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4) To determine the suitability of the treated marine clay as a pavement subgrade

III. MATERIALS AND METHODOLOGY

A. MATERIALS

1) MARINE CLAY

The marine clay that is used for the research has been acquired from the dump area of Kakinada Seaports Limited, Kakinada, Andhra Pradesh, India. The marine clay was collected from a depth of 2m at various test pits. The index and engineering properties of marine clay are given below.

Table 1: Grain Size Distribution of the Marine Clay

S.NO	Property		Marine clay (%)
1	Gravel		0
2	Sand		13.5
3	Finess	Silt	22
		Clay	64.5

Table 2: Properties of untreated marine clay

S.NO	Property	Symbol	Marine clay
1	Liquid Limit (%)	W_L	75.426
2	Plastic Limit (%)	W_P	30.89
3	Plasticity Index (%)	I_P	44.536
4	Soil Classification	-----	CH
5	Specific Gravity	G	2.37
6	Differential Free Swell (%)	DCDP	90
7	Optimum Moisture Content (%)	OMC	30.69
8	Maximum Dry Density (kN/m^3)	MDD	13.92
9	CBR (%)	CBR	1.583
10	Cohesion	c	2.741
11	Angle of Internal Friction (^{o})	Φ	120.624

2) FERROCHROME SLAG

Ferrochrome slag (FCS) is an industrial by-product generated during the production of ferrochrome alloy, which is primarily used in stainless steel manufacturing.It is formed when chromite ore ($FeCr_2O_4$) is smelted with coke, quartzite, and other fluxing materials in a submerged electric arc furnace. After the alloy is separated, the remaining molten material cools to form ferrochrome slag.

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Table 3: Chemical Properties of Ferrochrome slag

S. No	Content	Percentage
1	SiO_2	27.57
2	Al_2O_3	24.73
3	MgO	22.78
4	Cr_2O_3	9.35
5	CaO	9.23
6	FeO / Fe_2O_3	3.91
7	MnO	2.43

3) ZYCOBOND

Zycobond is a polymer-based soil stabilizing chemical developed to improve the engineering properties of weak soils.When mixed with soil, Zycobond interacts with the clay minerals through ionic exchange and polymer bonding, reducing the repulsive forces between particles and promoting flocculation and aggregation.

Table 4: Chemical Properties of zycobond

S. No	Components	Percentage
1	Quaternary Ammonium compounds	1 to 5
2	Methanol	0.1-0.2
3	Acetic acid	0.2-1
4	Acrylic Co polymer	34-36
5	Water	62-65

Fig-1 High Carbon Ferrochrome slag

Fig-2 Zycobond

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B. METHODOLOGY

The tests such as Differential Free Swell, Atterberg Limits (i.e. Liquid Limit & Plastic Limit), Optimum Moisture Content & Maximum Dry Density, California Bearing Ratio, Triaxial test are conducted on the soil samples with different proportions of FCS and Zycobond to test their suitability as stabilizing agents for soil to use as subgrade.

IV. RESULTS AND DISCUSSIONS

A. Treated with Ferrochrome slag

The Marine clay was treated with FCS with varying percentages of 4%, 8%, 12%, 16%, and 20%. Laboratory tests have been conducted and the results have been displayed below.

1) Liquid Limit, Plastic Limit, and Plasticity Index

The respective liquid limit, plastic limit, and plasticity index of varying FCS percentages are shown below.

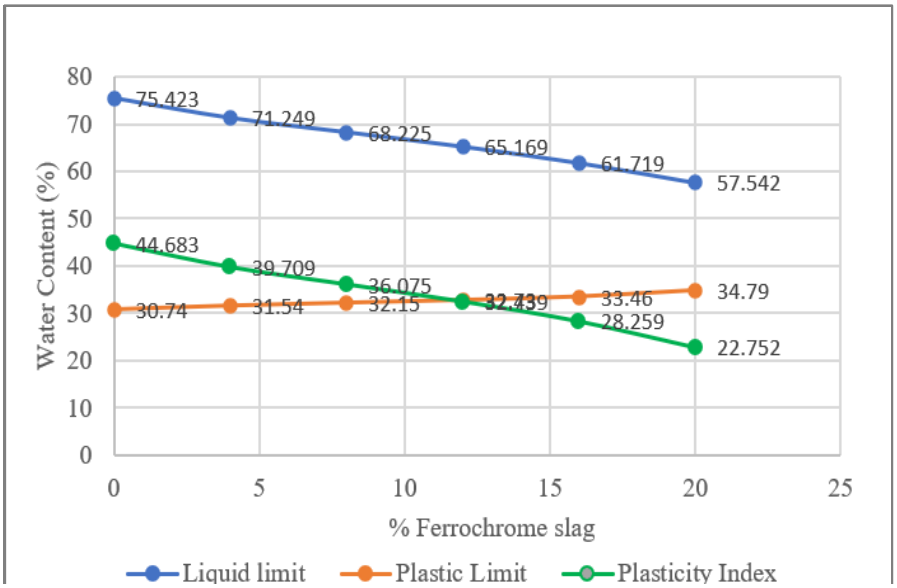

Plate 1: Liquid Limit, Plastic Limit, and Plasticity Index of Marine clay treated with various percentages of Ferrochrome slag

2) Differential Free Swell

The DFS values for the respective percentages are shown below.

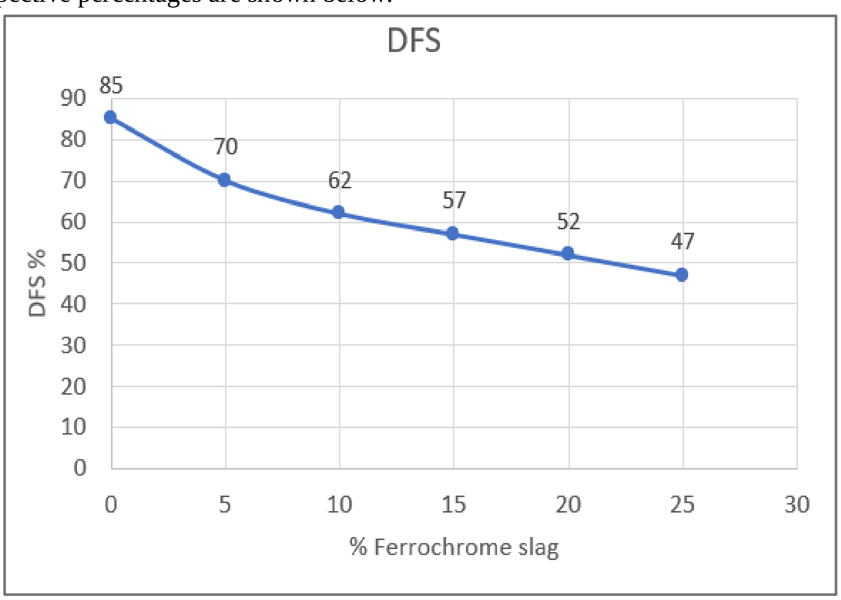

Plate 2: Differential Free Swell of Marine clay treated with various percentages of FCS.

3) Optimum Moisture Content & Maximum Dry Density

The MDD & OMC values for the marine clay treated with FCS are shown below.

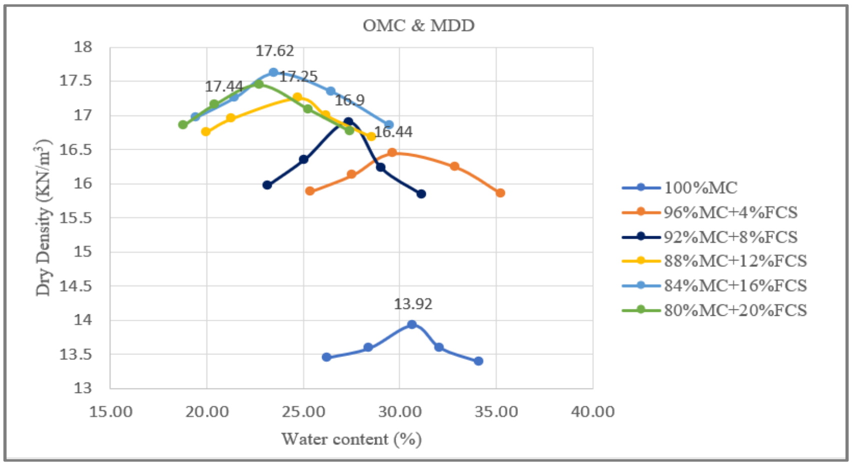

Plate 3: Optimum Moisture Content and Maximum Dry Density for Marine clay treated with various percentages of FCS.

4) California Bearing Ratio

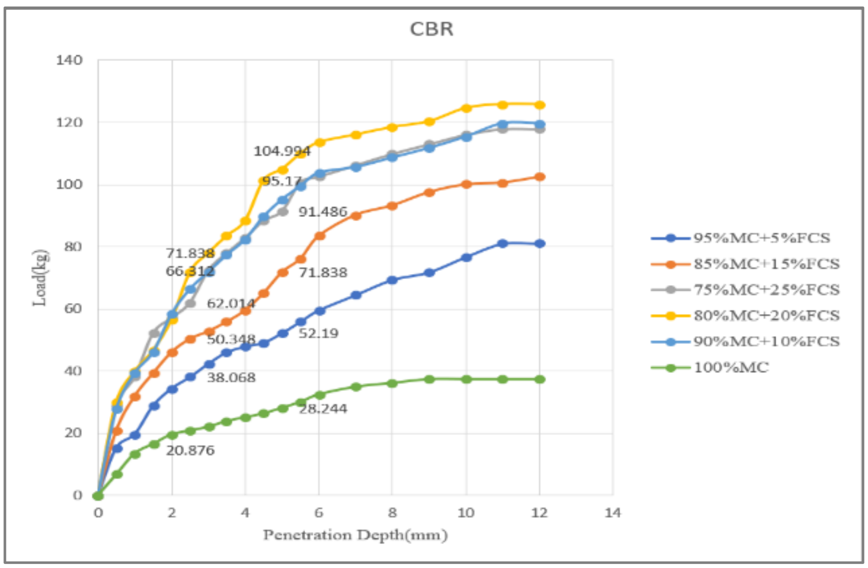

Plate4: Load vs Penetration curves of CBR tests conducted on Marine Clay treated with various percentages of FCS.

Discussion 1

The soil can be used as subgrade for flexible pavements should possess the minimum CBR value of 8% as per the IRC 37- 2012 codes of practice.

In the present study, the marine clay treated with an optimum of 16% Ferro chrome slag has exhibited a CBR value of 5.243%. Hence, this treated marine clay is not suitable as subgrade for flexible pavements as per the IRC 37- 2012 codes of practice.

Further, the present investigation has been continued by using Zycobond as a chemical admixture to improve the CBR value of Ferrochrome slag treated marine clay.

B. Treated with Zycobond

The marine clay is further treated with Zycobond in addition to the Ferrochrome slag to obtain more strength with varying percentages of 1%, 1.5%, 2%, 2.5% and 3%.

1) Liquid Limit, Plastic Limit, and Plasticity Index

The respective liquid limit, plastic limit, and plasticity index of varying Zycobond percentages are shown below.

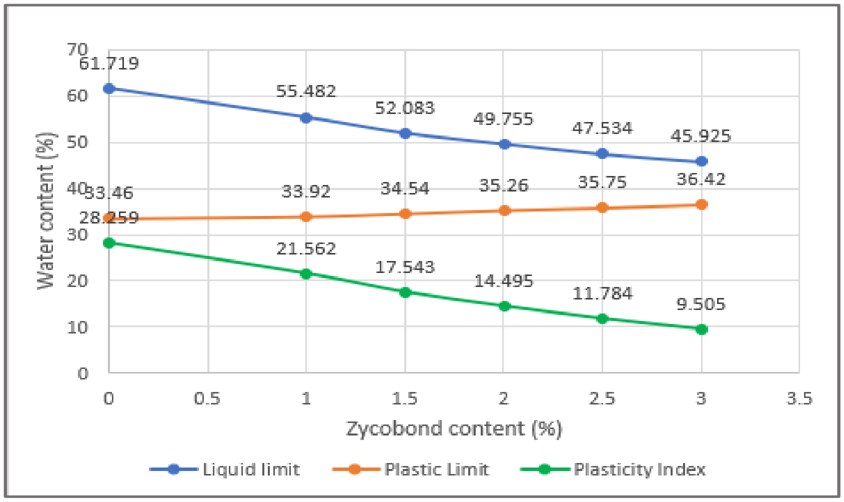

Plate5: Liquid Limit, Plastic Limit, and Plasticity Index of Marine clay treated with various percentages of Zycobond

2) Differential Free Swell

The DFS values for the respective percentages are shown below.

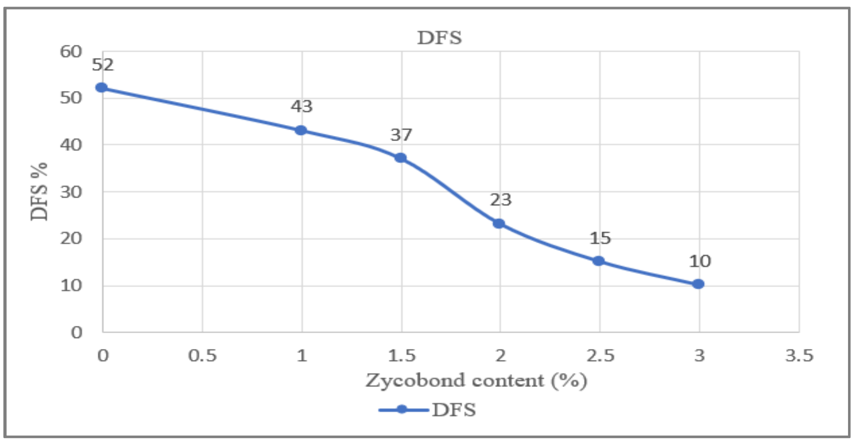

Plate6: Differential Free Swell of Marine clay treated with various percentages of Zycobond.

3) Optimum Moisture Content & Maximum Dry Density

The MDD & OMC values for the marine clay treated with Zycobond are shown below.

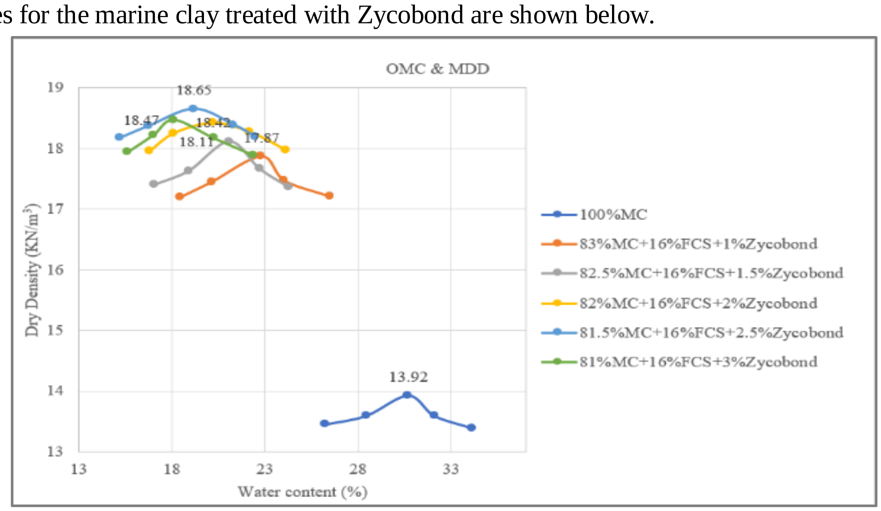

Plate7: Optimum Moisture Content and Maximum Dry Density for Marine clay treated with various percentages of Zycobond.

4) California Bearing Ratio

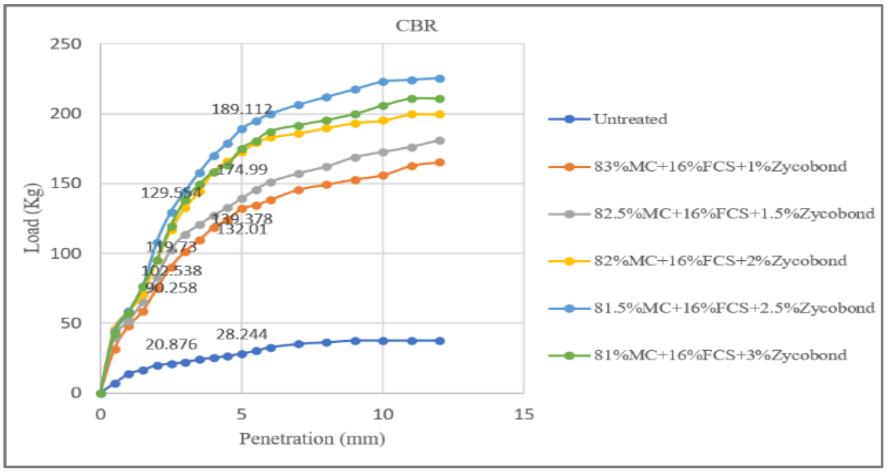

Plate8: Load vs Penetration curves of CBR tests conducted on Marine Clay treated with various percentages of Zycobond.

Discussion 2

The soil can be used as subgrade for flexible pavements should possess the minimum CBR value of 8% as per the IRC 37- 2012.

In the present study, the marine clay treated with an optimum of 16% Ferrochrome slag and 2.5%Zycobond has exhibited a CBR value of 9.456%. Hence, this treated marine clay is suitable as subgrade for flexible pavements as per the IRC 37- 2012 codes of practice.

Table-5:Laboratory test results of The Untreated and Treated Marine Clay with 16% Ferrochrome slag along with 2.5% Zycobond

S. No	Properties	Symbol	Marine clay	84% MC + 16%FCS	81.5%MC + 16% FCS +2.5 % Zycobond
1	Liquid Limit (%)	W_L	75.426	61.719	48.253
2	Plastic Limit (%)	W_P	30.89	33.46	36.54
3	Plasticity Index (%)	I_P	44.536	28.259	11.784
4	Soil Classification		CH	CH	CI
5	Differential Free Swell (%)	DFS	85	52	15
6	Optimum Moisture Content (%)	OMC	30.69	23.52	19.17
7	Maximum Dry Density (KN/m^3)	MDD	13.92	17.62	18.65
8	California Bearing Ratio (%)	CBR	1.584	5.243	9.456
9	Angle of internal friction (^{o})	Φ	2.741	5.547	6.952
10	Cohesion (kN/m^2)	c	120.62	91.25	82.95

V. CONCLUSION

The following results were derived by stabilizing the marine clay using Ferrochrome slag and Zycobond.

1) It is observed from the laboratory test results that the Liquid limit of Marine Clay has been decreased by 18.16% on the addition of 16% FCS and it has been further decreased by 36.02% with an addition of 2.5% Zycobond.

2) It is observed from the laboratory test results that the Plastic limit has been increased by 8.84% on addition of 16% FCS and it has been further increased by 18.86% with an addition of 2.5% Zycobond.

3) It is noticed that the Plasticity Index has been decreased by 36.75% on addition of 16% FCS and it has been further decreased by 73.63% with addition of 2.5% Zycobond.

4) It is noticed from the laboratory test results that the Differential Free Swell of Marine Clay has been reduced by 35.29% on the addition of 16% FCS and it has been further reduced by 82.35% with an addition of 2.5% Zycobond when compared with untreated Marine Clay.
5) It is observed from the laboratory tests that the OMC of the Marine Clay has been decreased by 23.85% on the addition of 16% FCS and it has been further decreased by 37.54% with addition of 2.5% Zycobond.
6) It is observed from the laboratory tests that the MDD of the Marine Clay has been increased by 26.58% on the addition of 16% FCS and it has been further increased by 33.98% with addition of 2.5% Zycobond.
7) It is observed that the CBR of the Marine Clay has been increased by 230.99% on the addition of 16% FCS and it has been further increased by 496.96% with addition of 2.5% Zycobond.

VI. VIABILITY

The addition of ferrochrome slag and Zycobond significantly enhanced the subgrade strength of marine clay by improving particle bonding and reducing plasticity. Laboratory results showed considerable increases in CBR strength compared to untreated soil. Therefore, the treated marine clay can be effectively used as a pavement subgrade material with improved load-bearing capacity and durability

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