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AN INVESTIGATION ON THE EFFICIENCY OF STEEL SLAG ON EXPANSIVE SOIL AS SUBGRADE FOR FLEXIBLE PAVEMENTS

Dr. D. Koteswara Rao[1], Khandavilli Venkata Sri Rama Manohar[2], B. Sowmya[3] Bandarupalli V. S. M. Bharadwaj[4], Yeluru Govindu Sai Sanjay[5]

[1]Professor, Head of the Department of Civil Engineering and OSD to the Hon'ble Vice Chancellor JNTUK, Kakinada, Andhra Pradesh, India

[2,3,4,5] Undergraduate Students, Department of Civil Engineering, University College of Engineering (A), JNTUK, Kakinada, Andhra Pradesh, India

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Abstract - *The technology used in road construction continually evolves to accommodate changing vehicular patterns, construction materials, and subgrade conditions. A significant portion of pavement failures is often linked to poor subgrade conditions, with expansive soil subgrades presenting particularly challenging issues. These soils are prone to swelling and shrinking, leading to cracks, especially during the dry seasons or years, which are termed verticals. The extensive damage caused to highways built over expansive soil subgrades results in substantial financial losses worldwide, reaching millions of dollars. In countries like India, where expansive soils are widespread, rerouting highways to avoid these materials is nearly impossible. From recent studies, it is observed that, solid waste materials such as rice husk ash, fly ash, waste tire rubber chips, etc., are used for this intended purpose. Hence, by using industrial by-products viz., Steel slag as an admixture in such problematic soils is economical and beneficial. In the present study, an attempt has been taken to use the steel slag as an admixture on improving the strength characteristics of expansive soil to suite it as a sub grade for flexible pavements.*

***Key Words*: Expansive Soil, Steel Slag, Liquid Limit, Plasticity Index, Optimum Moisture Content, Maximum Dry Density, California Bearing Ratio, Flexible Pavement.**

1.INTRODUCTION

Expansive soils are characterized by significant changes in volume due to fluctuations in soil moisture. The foundations laid on expansive soil beds facing significant damages because of swelling and shrinkage phenomena of expansive soil due to the variation in temperatures. Typically, pavements on expansive subgrade soils exhibit early signs of distress, leading to pavement failures. Expansive soils often possess unfavorable engineering properties, such as low bearing capacity, instability, and excessive swelling, posing significant challenges to civil engineering structures, especially in case of pavement sub grades and foundations. A Numerous researchers have conducted extensive studies to address these issues for developing remedial measures to control the failures in pavements laid on expansive soil subgrades. The Soil stabilization emerges as a practical solution among various methods to mitigate the problems associated with expansive soils, offering an effective means of improving soil properties.

Comprising a significant portion of clay-sized particles, this soil exhibits a color spectrum ranging from black to chestnut brown. On an average, expansive soils cover approximately 20% of total land area in India. These soils are conducive to dry farming and support the cultivation of crops such as cotton, rice, jowar, wheat, cereals, and vegetables, owing to their high moisture retention capacity.

In semi-arid regions, over the past few decades, noticeable damages caused by the swelling and shrinking action of expansive soils have been observed, leading to the cracking and disintegration of channels, reservoir linings, pavements, building foundations, water lines, irrigation systems, sewer lines, and slab-on-grade structures.

One method used for stabilizing the expansive soils involves the application of chemical additives, including lime, cement, and fly ash. This technique has proven successful in numerous projects, mitigating swelling, reducing soil plasticity, improving soil workability, and enhancing soil strength. Lime stabilization involves three main processes: water absorption and chemical binding during the hydration of unslaked lime (CaO) into slaked lime ($Ca(OH)_2$), pozzolanic reactions between lime and clay minerals to bolster mechanical strength, and cation exchange between the additive and clay particles (Dr.D.S.V.Prasad and T.Yamini devi (2018))

One of the methods of treatment of expansive soil to make them fit for the construction purposes is called stabilization. According to Petry (2002), assortment of stabilizers can be grouped into:

- By-product stabilizers (Quarry dust, Fly Ash, Slag, Phosphor- gypsum, etc.)

- Traditional stabilizers (Cement, Lime, etc.)
- Non-traditional stabilizers (Polymer, Enzymes, etc.)[11].

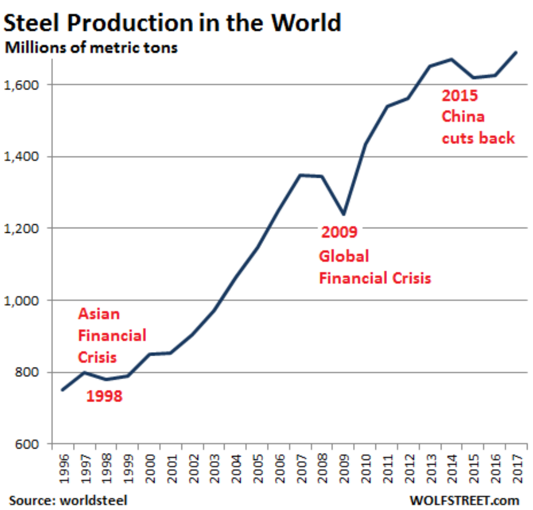
Lots of geo-environmental problems are a result of industrial by- products whose disposal as fills in disposal sites adjacent to the industries demand large chunks of land, which can otherwise be utilized for construction, growing of vegetation, etc. Various attempts have been taken by different researchers and organizations to utilize these by-products in civil engineering applications.

1.1 Steel Slag

The Steel slag, a by-product of steel manufacturing, emerges during the extraction of molten steel from impurities in steel-making furnaces. This slag exists initially as a molten liquid blend and constitutes a complex amalgamation of silicates and oxides that solidify on cooling. Currently, the vast majority of steel is manufactured in integrated steel plants employing variations of the basic oxygen process, or in specialized steel plants known as mini-mills, utilizing the electric arc furnace process. The obsolete open hearth furnace process is no longer in use.

Diverse grades of steel can be manufactured, and the characteristics of the steel slag can vary significantly with each grade. The classification of steel grades are high, medium, and low which are contingent upon the carbon content of the steel. The steels of high grade possess elevated carbon content. To diminish carbon levels in the steel, higher oxygen levels are necessary in the steel making process.

Production of steel slag from 1996 to 2017 worldwide



Source:http://ghovexx.blogspot.com/2018/06/who-dominates-global-steel-production.html

1.2 Expansive Soil

The Expansive soil used in the present investigation was collected from Amalapuram, East Godavari District, A.P, India. This expansive soil was collected at a depth of 1.0m from the ground level. The tests were carried out on the soil as per IS Codes of practice.

1.3 Objective of the Study

The objectives of the present experimental study are,

- To ascertain the characteristics of expansive soil.
- To assess the effectiveness of Steel slag as an admixture in improving the performance of expansive soil.
- To evaluate the performance of the treated expansive soil as a subgrade for flexible pavements.

Table-1: Properties of Expansive Soil

S.NO	PROPERTY	VALUES
1	**Grain Size Distribution** Gravel (%) Sand (%) Silt (%) Clay (%)	 0 4 23 73
2	**Atterberg limits** Liquid limit (%) Plastic limit (%) Plasticity Index (%)	 70 30 40
3	**Compaction Properties** Optimum Moisture Content (%) Maximum Dry Density (KN/m^3)	 25 16.18
4	Specific Gravity (G)	2.51
5	IS Classification	CH
6	CBR (%)	1.3
7	Differential Free Swell (%)	90
8	Cohesion (KN/m^2) Angle of Internal Friction (Φ)(^{0})	89.96 3
9	Natural Moisture Content (%)	62

2. REVIEW OF LITERATURE

2.1 Magdi Mohamed Eltayeb Zumrawi et al. (2017) investigated and found that the use of steel slag in stabilization of expansive soil in Sudan is highly economical and sustainable than cement stabilization. The study also states that with increase in steel slag content, Liquid Limit decreases, Plastic limit slightly increases, Differential Free Swell Decreases, Unconfined Compressive Strength (UCS) value increases.

2.2 Jun Wu et al. (2019) published on the modification of expansive soil by waste steel slag and its applications in highways. On the other hand, steel production has a variety of environmental consequences, including air pollution, wastewater contaminants, hazardous waste, and solid waste. Steel slag is well known for polluting fertile soils, surface waters, and groundwater when exposed to natural weathering conditions. Large quantities of steel slag, a by-product of the metallurgical industry produced during steel manufacturing processes, are dumped largely because of the difficulty involved in recycling. A typical expansive soil was sampled from Hefei city in China at a depth not less than 1.0 m under the ground surface. The soil was sealed in a polythene bag to avoid moisture loss during transportation. The physical properties of the steel slag obtained from the processing factory at Jiaxing city, China. The basic physical properties of the treated soils including Free swell ratio, California bearing ratio, Unconfined, consistency limits, and microstructure were evaluated to understand the engineering behavior and microstructural mechanism.

[AASS-the optimum adjusted and activated steel slag (containing 28.6% slag, 57.1% lime, 9.5% metakaolin and 4.8% Na_2SO_4)]

2.3 Umar Farook Ali et al. (2019) shows major volume changes due to change in the moisture content. When the soil is dry, they shrink and large crack is formed. This soil contains minerals such as montmorillonite that is capable of absorbing water. They collected expansive soil at POONDI. The soil was used in experimental program and it was classified as Inorganic clay of high plasticity (CH). Steel Slag was collected in industrial waste from "KOVAI RAJA TMT BARS" Coimbatore. Steel furnace slag typically forms a very angular, durable aggregate that makes it ideal for use in the transportation industry. They collected soil sample and oven dried for 24hrs and pulverized it. After that they conducted tests namely consistency limits, compaction proctor, unconfined, free swell and specific gravity. They conducted tests for different contents of soil and steel slag (0%,2%,4%,6%,8%). The value of UCC is increased adding a steel slag in percentage of 4% steel slag. Further increasing the percentage, the UCC value is to be decreased. The cohesion goes on decreasing and the angle of internal friction goes on increasing with the increase in percentage of addition of steel slag. The index properties of liquid limit, shrinkage limit, plastic limit and swelling index is decreased by adding a steel slag.

2.4 Worku Firomsa Kabeta et al. (2023) published about stabilizing expansive soil using steel slag. The presence of montmorillonite clay minerals in expansive soils makes them problematic in nature has a high tendency to volume change upon a change in moisture content, which is known as swelling potential. The steel industry is considered essential for a country like Ethiopia, which aspires to undergo a rapid process of industrialization and economic transformation. Steel slag from this industry was affecting the surrounding environment, and there was a need to minimize this waste by recycling for sustainable development. The suitability of steel slag in stabilizing expansive soil found in Ethiopia, specifically in Jimma town. The soil sample is taken from a depth of 1.5 m below the ground surface and kept in bags to maintain their natural moisture content. The steel slag used in this study was produced in Ethiopia by the Ethiopian Steel Company. The soil used in the experiments has a free swell test of 104.6%, indicating that it is expansive in a high range. The type of soil is highly expansive clay. This study concludes that steel slag is a cost-effective material for improving soil geotechnical properties and a viable option for reducing the environmental impact of steel slag waste.

3. EXPERIMENTATION

Different Tests were conducted in the laboratory on the Expansive soil to study the behavior of expansive soil when it is treated with different percentages of Steel Slag.

The Index and engineering properties were calculated for the untreated expansive soil and expansive soil treated with percentage variation of steel slag as per IS codes of practice.

3.1 Atterberg Limits

3.1.1 Liquid Limit

The liquid limit is defined as the moisture content at which the soil changes from the liquid state to the plastic state, which corresponds to 25 blows applied in a standard liquid limit apparatus just to close a groove of standard dimensions cut in the sample by the grooving tool by a specified amount.

The liquid limit is determined according to the specifications outlined in IS: 2720 (part 5)-1980.

3.1.2 Plastic Limit

The plastic limit is the moisture content at which a soil, when rolled into a thread of the smallest diameter possible, begins to crumble and reaches a diameter of 3mm. The plastic limit (W_P) is represented as a whole number by averaging the moisture contents at which this crumpling occurs.

3.2 Modified Proctor Compaction Test

The maximum dry density (MDD) and Optimum Moisture Content (OMC) of the soil are determined through compaction tests, following the procedure outlined in the Indian standard codes of practice IS: 2720 (Part VIII)-1983.

Fig.2: Authors performing Modified Proctor Compaction

3.3 California Bearing Ratio (CBR) Test

The California Bearing Ratio (CBR) serves as a measure of the shearing resistance of a material under controlled density and moisture conditions. A load-penetration curve is plotted for each specimen on a natural scale. From these curves, the CBR values are calculated for 2.5 mm and 5.0 mm depths of penetration.

Fig.1: Authors conducting CBR test

Table.2 present the mix proportions for the stabilization of expansive soil with percentage variation of steel slag.

Table-2: Mix Proportions for testing

S.NO	Mix Proportions
1	Expansive Soil
2	90% Expansive Soil + 10% Steel Slag
3	85% Expansive Soil + 15% Steel Slag
4	80% Expansive Soil + 20% Steel Slag
5	75% Expansive Soil + 25% Steel Slag

4. RESULTS AND DISCUSSION

4.1 Compaction Test Results

Table-3: OMC and MDD values of untreated and treated expansive soil

S.NO.	Mix proportion	Optimum Moisture Content (%)	Maximum Dry Density (g/cc)
1.	100% ES	24.65	1.649
2.	90%ES+10%SS	20	1.695
3.	85%ES+15%SS	19.17	1.778
4.	**80%ES+20%SS**	**18.54**	**1.83**
5.	75%ES+25%SS	17.54	1.75

Table 3 show that the OMC values decreases from 24.65% to 17.54% on addition of steel slag from 0% to 25%. The MDD values of the treated expansive soil was observed to be increased from 1.649 g/cc to 1.83 g/cc on addition of Steel slag from 10% to 20% and decreased to 1.75 g/cc on further addition of 25% steel slag.

The optimum mix proportion is observed by

80% Expansive Soil +20% Steel Slag.

4.2 CBR Test Results

Table-4: CBR Test Results for different mix proportions

S.NO.	Mix proportion	CBR (%)
1.	100% ES	1.34
2.	90%ES+10%SS	3.59
3.	85%ES+15%SS	4.03
4.	**80%ES+20%SS**	**8.07**
5.	75%ES+25%SS	6.27

Table-4 shows that CBR is increased from 1.34% to 8.07% after adding Steel slag from 0% to 20% and decreased to 6.27% of adding 25% steel slag.

The optimum mix proportion is given by 80% Expansive Soil with 20% Steel Slag.

4.1 Consistency Limits Results

Table-5: Consistency Limits Results for optimum mix proportion

S.NO.	Mix Proportion	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
1.	100% ES	70	30	40
2.	80%ES+20%SS	44	32	12

Table-5 shows the consistency limits of untreated soil along with optimum mix proportion. When the optimum admixture proportion is added, the Liquid Limit decreased from 70% to 44%, Plastic Limit decreases from 30% to 32%. Plasticity Index is decreased from 40% to 12%

According to Indian Standard Soil classification, the soil sample is classified as Highly Compressible Clay (CH).

Discussion:

As per IRC-37:2012 codes of practice, the subgrade soil should possess the minimum CBR value of 8%. In the present investigation, the expansive soil treated with an optimum of 20% Steel Slag has exhibited the CBR value of 8.07%. Hence this treated expansive soil is suitable as subgrade for flexible pavements.

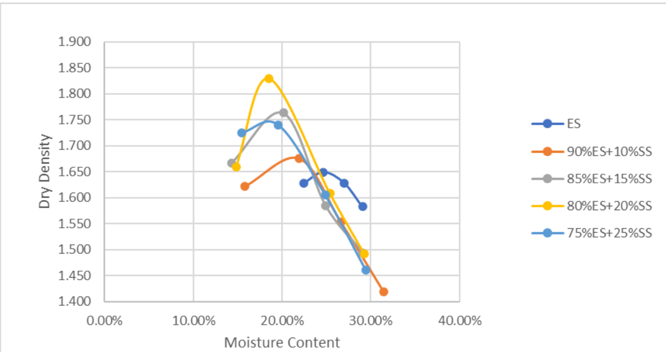


Chart-1: Variation of compaction test results with steel slag content (%)

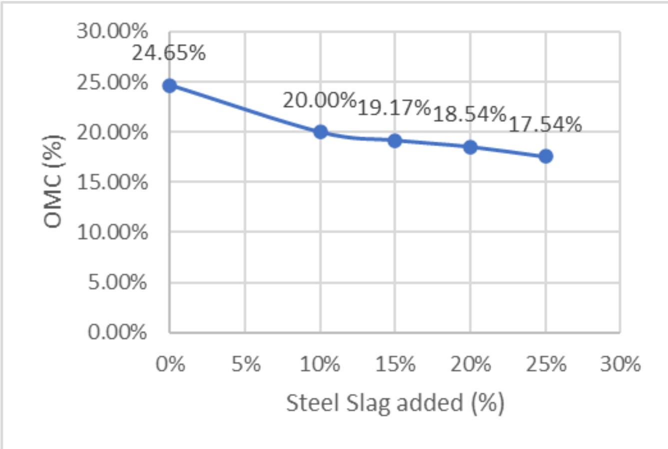


Chart-2: Variation of Optimum Moisture Content with Steel Slag content (%)

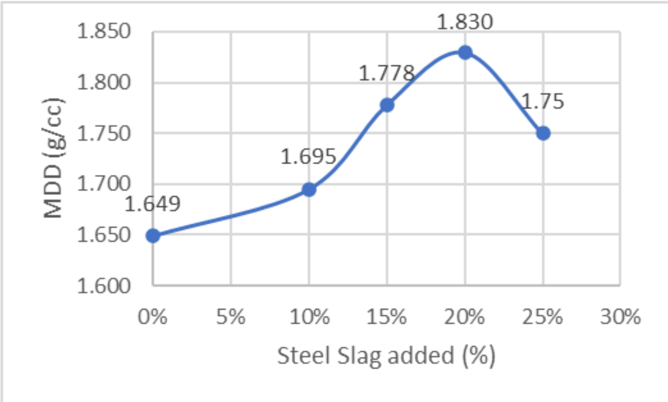


Chart-3: Variation of Maximum Dry Density with Steel Slag Content (%)

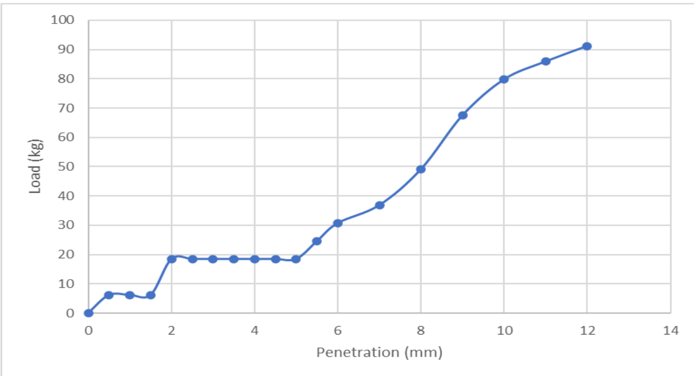


Chart-4: Relation between Load and Penetration for soil without admixtures

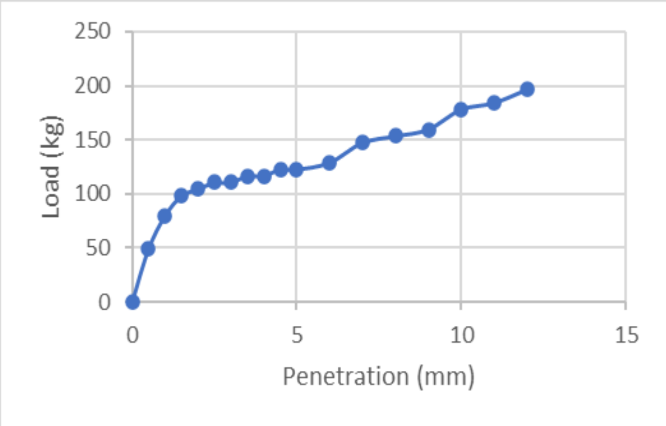


Chart-5: Relation between Load and Penetration for soil with optimum steel slag content (20%)

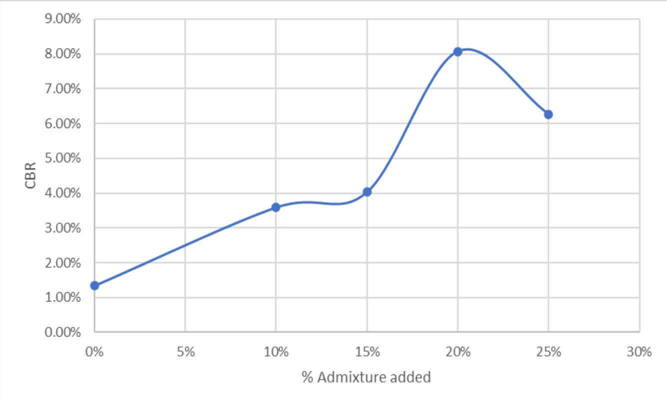


Chart-6: Variation of CBR values with percentage variation of Steel Slag (%).

Chart-7: Variation of Differential Free Swell with percentage variation of steel slag (%)

Table-6: COMPOSITE TABLE OF RESULTS COMPARING UNTREATED EXPANSIVE SOIL TO EXPANSIVE SOIL TREATED WITH 20% STEEL SLAG

S.NO	PROPERTY	UNTREATED EXPANSIVE SOIL	EXPANSIVE SOIL TREATED WITH 20% SS
1	**Atterberg limits** Liquid limit (%) Plastic limit (%) Plasticity Index (%)	70 30 40	44 32 12
2	**Compaction Properties** Optimum Moisture Content (%) Maximum Dry Density (KN/m^3)	25 16.18	18.54 17.95
3	Specific Gravity (G)	2.511	2.651
4	IS Classification	CH	CI
5	CBR (%)	1.3	8.07
6	Differential Free Swell (%)	90	20
7	Cohesion (KN/m^2) Angle of Internal Friction (Φ)(^{0})	89.96 3	66.89 8

5. CONCLUSIONS

Conclusions of the various laboratory test results were presented.

- It is observed from the laboratory results that the Liquid Limit of the Expansive soil has been decreased by 37.14% on addition of 20% Steel Slag as an optimum when compared with the untreated expansive soil.
- The plasticity Index of the Expansive soil has been improved by 70% on treating expansive soil with 20% Steel Slag when compared with the untreated expansive soil.
- The DFS values of treated expansive soil has been improved by 72.72% when compared with the untreated expansive soil
- The Optimum Moisture Content (OMC) has decreased by 3.89% on treating the expansive soil with 20% Steel Slag when compared with untreated expansive soil.

- The Maximum Dry Density (MDD) has increased by 0.202 g/cc on treating the expansive soil with 20% Steel Slag when compared with untreated expansive soil.
- It is noticed that the CBR value of the expansive soil has been improved by 83.79 % on treating it with 20% Steel Slag when compared with untreated expansive soil.

6. SCOPE FOR FURTHER STUDY

- Further laboratory investigations can be carried out with the addition of various chemicals such as $FeCl_3$, $MgCl_2$, $CaCl_2$ with expansive soils along with Steel Slag to improve strength characteristics.
- Further Laboratory investigations can be carried out by the addition of various other industrial wastes that are locally available and compare the characteristics with the characteristics obtained with steel slag.
- Field tests are performed to confirm the authenticity of the laboratory test results in the field.
- Laboratory cyclic plate load test should be conducted to know the performance of the expansive soil as sub-grade of flexible pavements under cyclic pressures.
- Laboratory Cyclic plate load test can be conducted by using Geotextiles as Reinforcement and separator.

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BIOGRAPHIES:

NAME: DR. D KOTESWARA RAO
Qualification: B.Tech, M.Tech (G.T.E), C.C.A & D.T.W, Ph.D,
Professor at JNTUK, KAKINADA

Name: Mr. K V S R MANOHAR
Qualification: B.Tech (Civil) U.G. Student at JNTUK, KAKINADA

Name: Ms. B SOWMYA
Qualification: B.Tech (Civil) U.G.
Student at JNTUK, KAKINADA

Name: Mr. Y G SAI SANJAY
Qualification: B.Tech (Civil) U.G.
Student at JNTUK, KAKINADA

Name: Mr. B V S M BHARADWAJ
Qualification: B.Tech (Civil) U.G.
Student at JNTUK, KAKINADA