Effect of Alkali-Activated Olivine in Unconfined Compressive strength and Microstructure of CL soil

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Abstract - *When olivine (Mg_2SiO_4) is activated with potassium hydroxide (KOH), it acquires the ability to improve the unconfined compressive strength of soil. This paper investigates the use of olivine for soil stabilization through alkaline activation by focusing on the role of different alkali activated olivine contents (5,10,15,20,25,30 wt%) in stabilizing native soil. It also studies the use olivine treated soil as a pavement material and liner. The impact of this work is far reaching and provides a new soil stabilization approach. Key advantages include significant improvements in soil strength with a lower carbon footprint compared with lime or cement stabilization. This achievement implies a tremendous effect of olivine on the strength behaviour of treated soil. These results provide essential information which is significant from an environmental perspective as it offers a low energy alternative to existing technologies, for soil stabilization.*

Key Words: **Soil Stabilization, Olivine, KOH, Alkali activation**

1. INTRODUCTION

Application of cement as binder in soil stabilization is a widely used method for ground improvement. However the high quantity of CO_2 released into the atmosphere is the main drawback of using cement. The cement industry produces 5% of global man-madeCO_2 emissions. Beside the emission of CO_2, another by-product of cement production is NO_2. Most of these nitrogen oxides are produced in cement kilns, which can contribute to the greenhouse effect and acid rain. Several attempts involving the use of alternative methods or by-products as partial or full replacements of cement as stabilizers have been made to alleviate this. In this respect, binders based on alkali-activated materials have received a significant interest due to their sustainability advantages.

The alkali activation is a process in which, the aluminosilicate materials (industrial wastes and by-products) were dissolved through an alkaline activator such as sodium hydroxide (NaOH) or potassium hydroxide (KOH) Alkali-activated materials may have low (e.g. fly ash class F and metakaolin) or high (e.g. ground granulated blastfurnace slag (GGBS) and fly ash class C) calcium contents. The formed geopolymeric gel can be viewed as an alkaline aluminosilicate base on amorphous Na+ or K+ aluminosilicate structure.

This report focuses on the use of olivine (Mg_2SiO_4) to provide a more sustainable approach for the preparation of alkali activated binders to be used in soil stabilization. Olivine is a magnesium silicate, whose deposits are globally located . It contains 45–49% magnesium oxide (MgO) and 40% SiO_2.

Its weak nesosilicate structure and the absence of strong Si–O–Si bonds leaves olivine susceptible to dissolution and subsequent chemical reaction. Its high SiO_2 and alkaline metal content makes this natural resource an ideal candidate for alkali activation. Due to its role as an effective source of MgO and SiO_2 with weak chemical bonds, olivine can be a good candidate for soil stabilization after being subjected to alkali activation. The aim of this study is to explore the use of olivine in the presence of KOH for the development of high strengths during soil stabilization. The behaviour of olivine treated soil was examined through UCS measurements and its effectiveness as pavement material was studied by conducting CBR test.

1.1 Olivine and its properties

Olivine has a high affinity for the adsorption of CO_2 in the presence of water. Similarly, the hydration product of MgO, brucite can carbonate to produce magnesite or hydrated magnesium carbonates such asnesquehonite, dypingite , and hydromagnesite. The carbonation of olivine has been reported to improve the unconfined compressive strength (UCS) and ultimate bearing capacity of soil.. Blencoe and Palmer [U.S. Patent No. 8,114,374 (2012)] reported the use of a strong base such as sodium hydroxide (NaOH) to break the chemical bond between MgO and SiO2. This leads to the production of $Mg(OH)_2$ and Na_2SiO_3. An intermediate step can involve the reaction of CO_2 with NaOH to improve the CO_2 adsorption potential. The reaction products are alkali-metal carbonate (Na_2CO_3) or bicarbonate ($NaHCO_3$) and silica in either a gelatinous or solid form (Blencoe and Palmer,U.S. Patent No. 8,114,374 (2012)). Due to its role as an effective source of MgO and SiO_2 with weak chemical bonds, olivine can be an ideal candidate for soil stabilization after being subjected to alkali activation and carbonation. Moreover, one of the great advantages of stabilizing soil using olivine as a binder in the presence of a strong alkali is that pretreatments, which are often energy intensive, are not required. This process can be induced by the introduction of NaOH to increase the carbonation potential of olivine.

This study aims to explore the carbonation of alkali-activated olivine used in soil stabilization. The behavior of olivine-treated soil was examined through UCS measurements before and after carbonation treatment.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Kaolinite

Table -1: Properties of soil

Properties of soil	
Specific Gravity	2.67
Liquid Limit (%)	33
Plastic Limit (%)	20.66
Plasticity Index (%)	12.34
Shrinkage Limit (%)	19.06
IS Classification	CL
Optimum Moisture Content	24.5
Maximum Dry Density	1.65
Percentage of Clay	68
Percentage of Silt	24.8
Percentage of Sand	7.2
UCC	0.634

2.1.2 Olivine

Table -2: Properties of Olivine

Properties	
Chemical Composition	**Value**
MgO	49
SiO_2	41
Fe_2O_3	9
Al_2O_3	0.5-2
3CaO	0.2
Melting Point	1600^0C
Free Silica Content	<0.1%
Bulk Density	3.2-3.4

2.2 Methods

2.2.1 Compaction Test (IS 2720 Part VII)

Three kilograms of soil is taken and the water is added to it to bring its moisture content. The mould with the base plate attached is weighed to the nearest 1g(M1). The extension collar is to be attached with the mould. Then the moist soil in the mould is compacted in three equal layers, each layer being given 25 blows from the 2.6 kg rammer dropped from a height of 310 mm above the soil. The extension collar is removed and the compacted soil is leveled of carefully to the top of the mould by means of straight edge. Then the mould and soil is weighed to the nearest 1g (M2). The soil is removed from the mould and a representative soil sample is obtained to determine the water content by oven drying. Steps are repeated after adding suitable amount of water to the soil in an increasing order. Bulk density in g/cm³, at each compacted soil is calculated from the equation;

$$\text{Bulk density} = \frac{(M2-M1)}{Vm}$$, Vm = volume of the mould

The dry density in g/cm³ is calculated from the equation;

$$\text{Dry density} = \frac{(100 \text{ X Bulk density})}{(100+w)}$$, w = moisture content (%)

The dry densities obtained in series of determinations are plotted against the corresponding moisture content. A smooth curve is then drawn through the resulting points and the positions of the maximum on this curve is determined to obtain the maximum dry density and the corresponding water content as optimum moisture content.

2.2.2 Unconfined Compression Test (IS 2720 Part X)

Unconfined compression test is a special case of triaxial compression test in which a cylindrical soil specimen was subjected to an initial compressive force without any lateral confining pressure. In unconfined compressive test, about 150 g of soil sample taken in a pan and was well mixed with 305 of water. The mixed soil was filled in a split mould of standard dimensions using spatula. While preparing the specimen care should be taken that no air bubbles are entrapped between the soil grains. Using a coning tool both ends of the specimen are shaped so as to make it supported on the conical seating. The mould was opened out and the specimen is taken out from it. It is placed between the conical seating. The dial gauge on the proving ring was set to zero. A dial gauge is used for measuring deflection proving ring corresponding to the deflection of the soil sample at 50 division's intervals. The loading may be continued up to the failure of the specimen. From proving ring readings, the compressive loads applied to the specimen were calculated. The deflection on the specimen can also be calculated from the observed reading of dial gauge. A graph is plotted with deflection on X- axis and the corresponding load on Y-axis. From load deflection graph , the unconfined compressive strength of soil can be calculated from the load at failure.

Unconfined compressive strength =

$$\frac{(\text{load at failure})}{(\text{Area of cross section})} = \frac{P}{A}$$

2.2.3 SEM Analysis

Scanning Electron Microscopy (SEM) is a test process that scans a sample with an electron beam to produce a magnified image for analysis. The method is also known as SEM analysis and SEM microscopy, and is used very effectively in microanalysis and failure analysis of solid inorganic materials. Electron microscopy is performed at high magnifications, generates high-resolution images and precisely measures very small features and objects. The SEM equipment includes a variable pressure system capable of holding wet and/or non-conductive samples with minimal preparation. The large sample chamber allows for the examination of samples up to 200 mm (7.87 in.) in diameter and 80 mm (3.14 in.) in height. High-resolution images are produced during SEM analysis at magnifications from 5x to 300,000x. Scanning Electron Microscopy uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. In most SEM microscopy applications, data is collected over a selected area of the surface of the sample and a two-dimensional image is generated that displays spatial variations in properties including chemical characterization, texture and orientation of materials. The SEM is also capable of performing analyses of selected point locations on the sample. This approach is especially useful in qualitatively or semi-quantitatively determining chemical compositions, crystalline structure and crystal orientations.

3. RESULTS

3.1 Effect on Compaction characteristics: The compaction characteristics of the soil are determined according to IS 2720(Part VII). For this 5,10,15,20,25,30 % of Olivine was added to the soil and samples were prepared with and without alkali activation and tested.

Table -3: Variation of OMC

CURING TIME	OMC (%)					
	5	10	15	20	25	30
Zero Day	23.5	22.8	22.5	22.1	22.6	22.4
Zero Day AA	23.1	22.5	21.8	21.6	22.4	22.3
7 Day	23	22.3	21.4	21.2	22.1	22
7Day AA	22	21.4	20.9	20.4	20.8	21.2
14Day	21.8	21.2	20.7	20.2	20.6	20.5
14Day AA	21.2	20.8	20.5	20	20.5	20.2
28Day	20.7	20.4	20.1	19.8	20	19.8
28Day AA	20.4	20	19.4	19.3	**19.2**	19.6

Table -4: Variation of MDD

CURING TIME	MDD (g/cc)					
	5	10	15	20	25	30
Zero Day	1.65	1.66	1.68	1.7	1.72	1.7
Zero Day AA	1.67	1.7	1.73	1.74	1.75	1.73
7 Day	1.67	1.72	1.74	1.76	1.78	1.74
7Day AA	1.72	1.74	1.75	1.79	1.82	1.75
14Day	1.73	1.75	1.77	1.82	1.85	1.77
14Day AA	1.75	1.79	1.82	1.86	1.88	1.84
28Day	1.76	1.8	1.84	1.88	1.9	1.82
28Day AA	1.78	1.84	1.86	1.9	**1.92**	1.84

3.2 Effect on Unconfined Compressive strength: For conducting the study samples were prepared with 5,10,15,20,25,30 % Olivine .To study the effect of curing on the strength characteristics 7, 14 and 28 days curing were provided for each percentage samples with and without alkali activation

Table -5: Variation of UCC (KN/m^2)

CURING TIME	OLIVINE CONTENT					
	5%	**10%**	**15%**	**20%**	**25%**	**30%**
Zero Day	122	125	130	151	162	142
Zero Day AA	130	142	150	158	175	149
7 Day	160	180	190	195	210	190
7 Day AA	220	260	305	325	350	320
14 Day	202	260	308	330	354	315
14Day AA	208	298	325	352	388	348
28 Day	250	310	330	360	395	320
28 Day AA	260	330	365	430	**475**	395

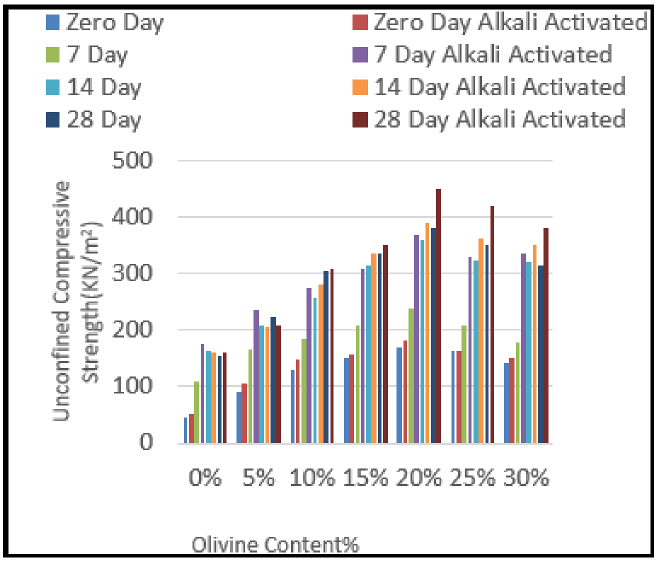

Chart -1: Variation of UCS

- It was studied that in the soil, without alkali activation, the strength improvement was comparatively less and this was due to low reactivity of Mgo at earlier ages and since hydration was not enough, alkali activation was required.
- After alkali activation, strength increased with increase in olivine content upto 20% in Amaravila soil and 25% in Kaolinite.
- In the presence of an alkali activator Mg offers additional nucleation sites and forms magnesium silicate gel. It also leaches out Si and Al from soil and form Alumina-silicat-hydrate gel.

3.3 SEM Analysis

Figure 1 shows the microstructure of soil and figure 2 show the 25% olivine treated soil alkali activated with KOH. A comparison of Figs, 1 and 2 reveals how the olivine fills the pores of the soil as a result of its hydration and pozzolanic reaction within the soil.

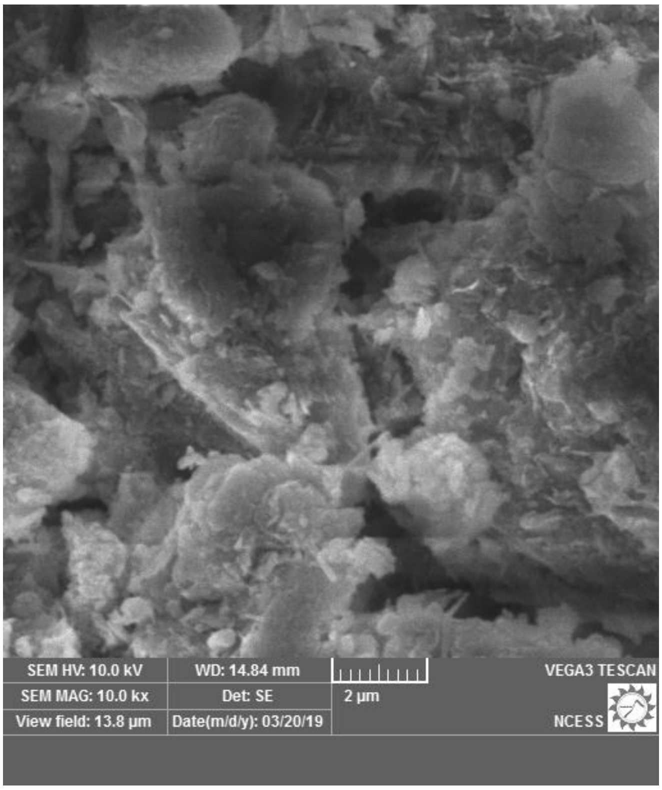

Fig -1: SEM image of untreated soil

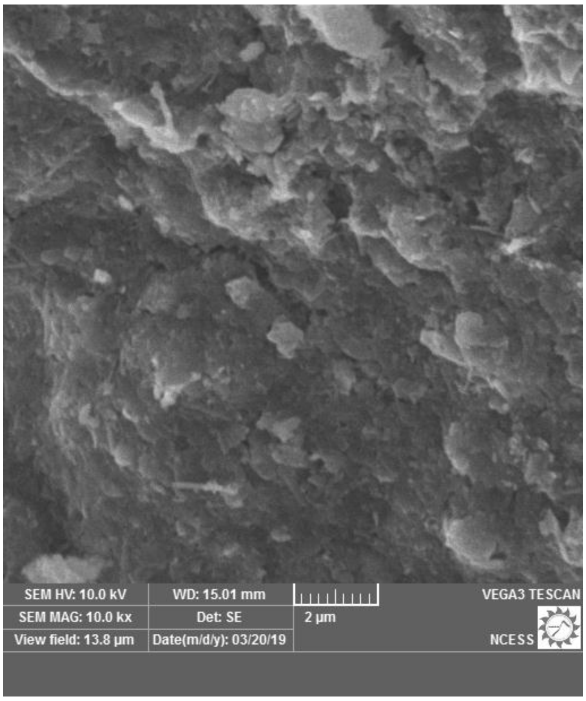

Fig -2: SEM image of treated soil

3. CONCLUSIONS

This study investigated the potential of Olivine as a sustainable binder in improving the properties of clay. The following conclusions can be deduced from the study.

- Addition of Olivine increased the maximum dry density and reduced the optimum moisture content of the soil.
- Strength of Olivine treated soils was found to improve in the presence of an alkali activator.
- There was decrease in OMC upto 25% after which it increased
- MDD of the soil increased uptp 25% addition of Olivine and marked a decrease after it.
- Based on strength improvement the optimum concentration of olivine was found to be around 25%.
- SEM analysis reveals how the olivine fills the pores of the soil as a result of its hydration and pozzolanic reaction within the soil.

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