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Studies on the Enhancement of Soil Strength by Inclusion of Chemicals blended with MFGGBS

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Abstract - Expansive soils cover a large part of country. It is required to use potentially cost effective and locally available material from wastes as a stabilizer to improve the property of soil. This study aims to investigate feasibility of using $MgCl_2$ and $CaCl_2$ (0.5%, 1%, 1.5% & 2%) and MFGGBS (4%, 8% & 12%) to improve the geotechnical properties of the soil. Testing parameters are geotechnical properties, index properties and environmental properties. Such as geotechnical properties are Atterberg's limits, compaction, consolidation, and unconfined compressive strengths have been performed to find out the effects of strength and swelling properties. Result indicate the unconfined compressive strengths increase with increase in percentage of chemical and swelling percentage is decreased with increase of admixtures of $Mgcl_2$, $Cacl_2$ and MFGGBS. The result show that the $Mgcl_2$, $Cacl_2$ and MFGGBS can be used as stabilized materials.

***Key Words*: Expansive Soil; Calcium Chloride; Magnesium Chloride; Micro Fine Ground Granulated Blast Slag.**

1. INTRODUCTION

The Stabilization of naturally occurring of soils has been performed over a several years. Soil stabilization may be defined as the alteration or preservation of one or more soil properties to improve the engineering characteristics and performance of a soil. Soil stabilization refers to the procedure in which a special soil, cementing material, or other chemical materials are added to a natural soil to improve one or more of its properties (Habiba Afrin 2017). In the field construction activities, many times civil engineer has to encountered with this expansive soil because in field either it used as construction material e.g. dams, embankment, etc. This necessitates proper remedial measure to modify the soil with respect to control on swelling and increase in strength. Many researchers and investigators have developed various approaches and methods of improving the undesirable characteristics of expansive soil. (S. R. Khandeshwar et al.2016). Various types of additives (e.g. cement, lime, and bitumen) and locally available wastes materials (e.g. bagasse ash, fly ash, slate dust, rice husk ash etc.) are used for modification/stabilization of soils (Alexander Joseph et al 2018).In general, stabilizing agents may be divided into two broad categories, based on the stabilization mechanisms utilized when the agents are incorporated into a soil or aggregate. Active stabilizers produce chemically induced cementing reaction within the soil or aggregate, which in turn produces desirable changes in engineering characteristics of the stabilized soil or aggregate system. Inert stabilizers do not react chemically with the soil or aggregate. Rather, stabilization is obtained as a result of binding together and/or water-proofing the soil or aggregate with the inert stabilizer. Many stabilizers display various combinations of active and inert characteristics (Anderson , al.1978).

2. Materials and methodology

The Expansive soil sample used for this study was collected by method of disturbed sampling from an Expansive soil formation in **Ariyankuppam,** Puducherry on a (Longitude 77.80E Latitude 11.89N). The samples were collected in large bags while a sizeable amount was collected and sealed airtight in a polythene bag in order to obtain the natural moisture content immediately upon returning to the laboratory. The soil was transported down to the Pondicherry Engineering College, of the Department of Civil Engineering, Puducherry, thereafter they were air dried completely and pulverized and passed through a U.S. standard sieve No. 4 (4.75 lm aperture).

Table -1: Engineering properties of the soil

S.No	Properties	Typical Value
1	Plastic Limit	32.96
2	Liquid Limit	72.48
3	Plasticity Index	39.52
4	MDD, gm/cc	15.29
5	OMC %	22.31
6	Specific Gravity, G	2.47

2.1 Calcium Chloride

Calcium chloride is an inorganic salt, which is a by-product of sodium carbonate production. The use of calcium chloride in place of lime ''because it is more easily made into calcium charged supernatant than lime'' was established by **Petry and Armstrong.** Inasmuch as calcium chloride treated pavement roads minimizes frost, heave, and reduces freeze–

thaw cycles, thus reducing maintenance cost , the higher surface tension and lower freezing point of $CaCl_2$ compared to water makes it useful in frost control of subgrade soils(Alexander Joseph et al 2018). Generally speaking, calcium chloride mostly acts as an active stabilizer. Calcium chloride ($CaCl_2$) has been used primarily as a dust palliative in roadway maintenance as soil stabilization products. It has been shown to be effective not only for the development of strength, but also for dust control because its deliquescent nature tends to absorb atmospheric moisture and keep the fines from the soil surface (Hyung Jun Choi 2005). Reported that an increase in $CaCl_2$ content leads to an increase in dry density and a decrease in optimum moisture content resulting to greater strength and swelling behaviour of expansive soil decreased with increasing percentage of $CaCl_2$ (Alexander Joseph et al 2018).

2.2 Magnesium Chloride

Magnesium chloride has been used as an anti-icing agent on roads rather than as a soil stabilizer (Wan Hasmida Wan Hassan et al 2017).Magnesium chloride ($MgCl_2$) or bischofite, which belongs to the halide group, is known as a sea salt concentrate that originated from the Permian Period (nearly 200 million years ago). Needless to say, the main bischofite compound is magnesium chloride ($MgCl_2$, up to 350 g/L). The effects of $MgCl_2$ solution on the swell potential, strength characteristics, and dispersibility properties of soils (Nima Latif et al 2016). $MgCl_2$ usage is becoming more common owing to its potential to improve the geotechnical properties of problematic soil, and it is receiving increasing attention. In recent years, studies have been conducted to investigate strength characteristics and dispersibility properties of soils stabilized with magnesium chloride solution. The strength improvement of $MgCl_2$-stabilized organic soil is investigated via unconfined compressive strength (UCS) test (Wan Hasmida Wan Hassan et al 2017). **"GROUD GRANULATED BALLAST FURNANCE SLAG (GGBS)"** may be used as an admixture which is easily available. The general objectives of mixing chemical additive with soil are to improve or control volume stabilities, strength and stress-strain properties, permeability, and durability (J.P.Singh et al 2014).

2.3 MFGGBS (Micro Fine Ground Granulated Blast Slag)

MFGGBS used in this study is sampled from Nanjing Iron & Steel Group Corps. Its physical and chemical properties are Alkalinity, Specific surface area, Average grain size and pH (liquid to solid ratio = 1:1) (Ning-Jun Jiang et al 2018). Free swelling of the soil is decreased with the addition of micro fine slag. Mixing of micro-fine slag decreased the liquid limit, plasticity index and optimum moisture contents of the expansive soil (Rajesh Prasad Shukla et al 2016). The use of ground granulated blast furnace slag, an industrial by-product, is well established as a binder in many cement applications, the effect of GGBS on the strength properties of lime-stabilized sulfate-bearing clay soils. The effect of GGBS on plasticity and swell potential of the lime treated expansive soil with different sulfate concentrations and evaluation of the GGBS was addressed by measuring and analysing plasticity, linear shrinkage and swell potential of the lime-treated expansive soil with different sulfate concentrations in the absence and presence of GGBS (Ece Celik et al 2013).

2.4 Testing Methodology

Soil samples were collected from the field and preserved in desiccator for further testing. Firstly, index properties; Atterberg limits, in-situ moisture content, grain size distribution curve and maximum dry density of all the soil samples were determined in the laboratory as per the Indian standard codes. The plastic limit and liquid limit of micro-fine slag mixed soil were determined using the thread rolling method and Casagrande percussion method respectively. There are two methods available to estimate the shrinkage limit of fine-grained soil, namely, wax method and mercury method. The mercury device test method was used to assess the shrinkage limit. In this method, the total volume of specimen was determined when samples were dried out. Variation in the shrinkage limit of the soil samples were measured by changing the amount of micro fine slag in the soil sample.

The standard proctor tests were conducted on untreated soil and micro-fine slag. A sufficient quantity of water was added to the micro-fine slag mixed soil to enable smooth mixing and compaction. A metallic mold having inner diameter 38- and 76-mm length was used to prepare samples for the unconfined compressive strength tests. Samples were prepared for optimum moisture content and were compacted from both the ends to achieve a uniform compacted sample. The specimen was removed from the metallic mold using a hydraulic jack. The strain rate of 1.2 mm/min was selected for the UCS test (Rajesh Prasad Shukla et al 2016).

3. Results and Discussions

3.1 Effect of Calcium Chloride & Magnesium Chloride on Atterberg's Limits:

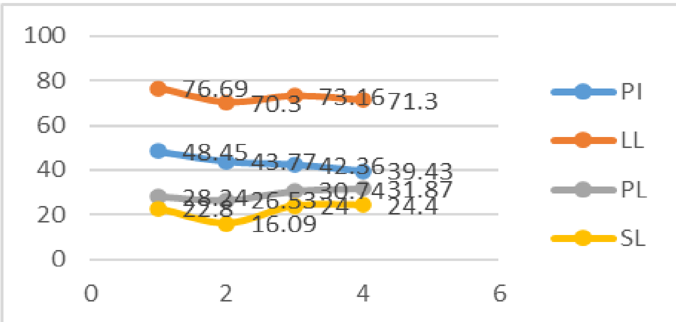

Chart -1: Effect of $Cacl_2$ & $Mgcl_2$ on L.L, P.L, S and P.I

Liquid limit was reduced from 76.69% to 71.3% on addition of 0.5% of $CaCl_2$ & $MgCl_2$ which is 7.3% reduction and an increase in value of liquid limit is observed on further addition of 0.5% of $CaCl_2$. Shrinkage limit increased to 24.4% from 22.8% (6.5% increase) on addition of 0.5% of $CaCl_2$ & $MgCl_2$. Plastic limit increased from 28.24% to 31.87% (12.8% increase) on addition of 1% of $CaCl_2$ & $MgCl_2$. Plasticity index reduced from 48.45% to 39.43% (18.61% reduction) with addition of 0.5% $CaCl_2$ & $MgCl_2$.

3.2Effect of Calcium Chloride & Magnesium Chloride on Compaction Parameters:

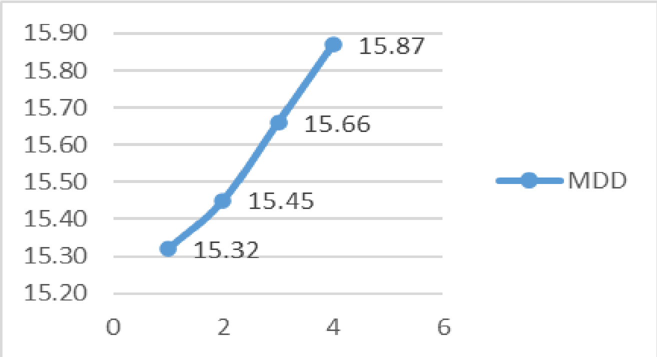

Chart -2: Effect of **$CaCl_2$** & $MgCl_2$ **on** MDD

Maximum dry density of 15.45 KN/m³ (marginal increase) is observed at water content of 21.60%when 1.0% of calcium chloride and magnesium chloride is added to soil sample and further increase in calcium chloride and magnesium chloride content is reducing the value of maximum dry density.

3.3 Effect of Calcium Chloride & Magnesium Chloride on Shear Strength Parameters:

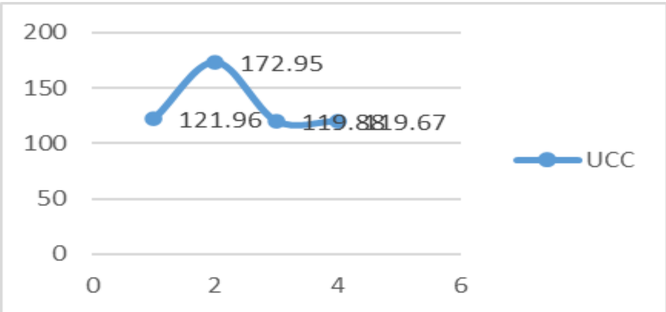

Chart -3: Effect of $CaCl_2$ & $MgCl_2$ on UCS

The value of unconfined compressive strength has been gradually increasing from 121.96KN/m² to 172.95KN/m² (80% increase) on addition of calcium chloride and magnesium chloride gradually from 0.5% to 1.0%.

3.4 Effect of MFGGBS on Atterberg's Limits:

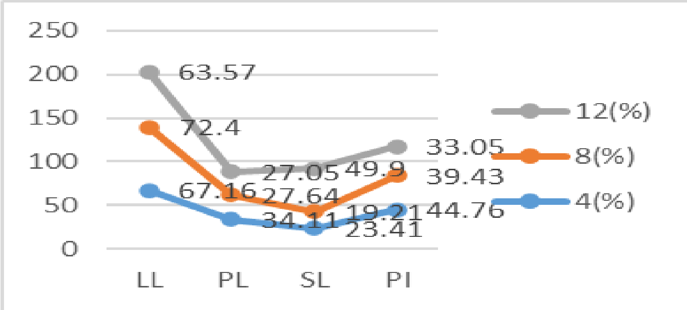

Chart -4: Variation of L.L, P.L, S.L and P.I with MFGGBS

A change in Liquid limit value from 67.16% to 63.57% (5.34% reduction) was observed on gradual addition of MFGGBS from 4% to 12%. Plastic limit was observed to increase from 34.11% to 27.05% (20.70% increase) on addition of MFGGBS gradually from 4% to 12%. Shrinkage limit was observed to increase gradually from 23.41% to 49.9% (54.06% increase) on addition of MFGGBS from 4% to 12%. Plasticity Index has reduced from 44.76% to 33.05% (26.19% reduction) which makes the soil to fall from very high degree of expansion category to high degree of expansion (based on P.I).

3.5 Effect of MFGGBS on Compaction Parameters:

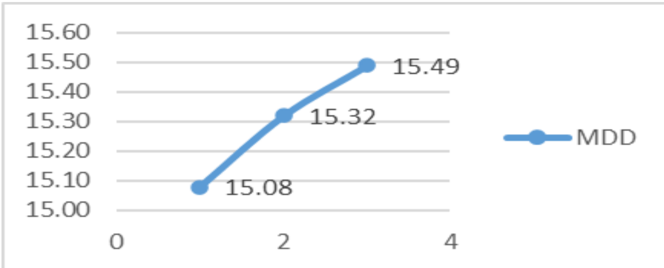

Chart -5: Effect of MFGGBS on MDD

Maximum dry density has observed to increase to15.49 KN/m³ with addition of 12% of MFGGBS.

3.6Effect of MFGGBS on Shear Strength Parameters:

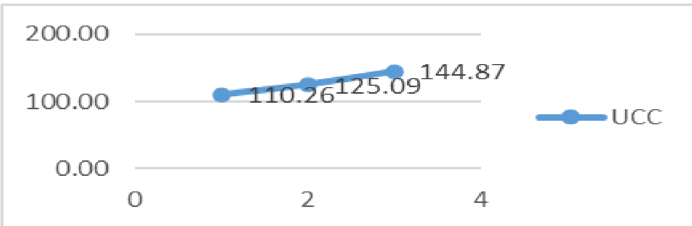

Chart -6: Effect of MFGGBS on UCS

The value of unconfined compressive strength has been gradually increasing from 110.26 KN/m² to 144.88 KN/m² (23.90% increase) on addition of 12% of MFGGBS but further increase in MFGGBS decreased the UCS value drastically.

3.7 Effect Of 4% MFGGBS and Varying Percentages of Calcium Chloride & Magnesium Chloride on Atterberg's Limits:

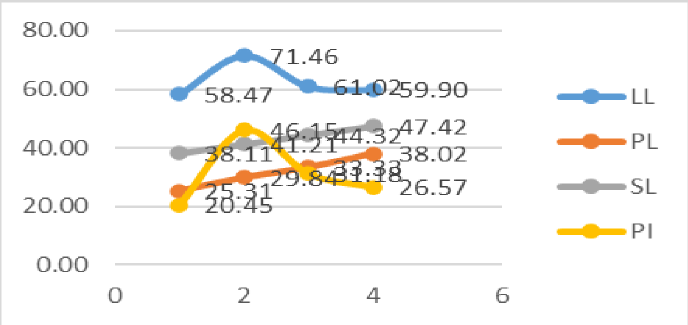

Chart -7: Variation of L.L, P.L, S.L and P.I with 4% MFGGBS + $MgCl_2$ $CaCl_2$

Initially when 4% MFGGBS is added with 0.5% Calcium Chloride and Magnesium Chloride the liquid limit was 71.46% and further addition of Calcium Chloride and Magnesium Chloride gradually to 10% decreased the value of liquid limit to 61.02% by which the soil falls in the category of high degree of expansion. Initially when 4% MFGGBS is added with 0.5% Calcium Chloride and magnesium chloride the plastic limit was 25.31% and further increase in Calcium Chloride and magnesium chloride percentage increased the value to 38.02%. Shrinkage limit was observed to increase gradually from 38.08% to 47.42% (19.87% increase) on addition of 0.5% Calcium chloride and magnesium chloride with 4%MFGGBS. Plasticity Index has reduced from 46.15% to 31.18% (32.54% reduction) which makes the soil to fall from very high degree of expansion category to high degree of expansion (based on P.I).

3.8 Effect Of 4% MFGGBS and Varying Percentages of Calcium Chloride & Magnesium Chloride on Compaction Parameters:

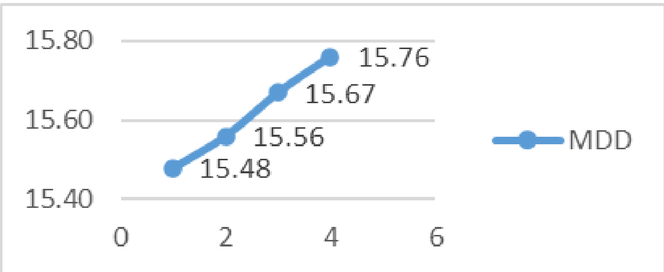

Chart -8: Variation of MDD with 4% MFGGBS + $MgCl_2$ $CaCl_2$ (0.5%, 1%, 1.5%, 2%)

Maximum dry density is observed to increase to 15.76 KN/m^3 with addition of Calcium chloride and magnesium chloride 0.5%,1.0%, 1.5% and 2% (marginal increase) keeping 4% MFGGBS as constant.

3.9 Effect Of 4% MFGGBS and Varying Percentages of Calcium Chloride & Magnesium Chloride on Shear Strength Parameters:

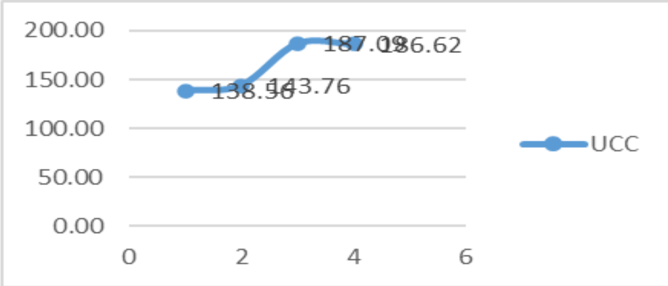

Chart -9: Variation of UCS with 4% MFGGBS + $MgCl_2$ $CaCl_2$ (0.5%, 1%, 1.5%, 2%)

The value of unconfined compressive strength has been gradually increasing from 138.56 KN/m^2 to 186.62 KN/m^2 on addition of 2% Calcium chloride and magnesium chloride of with 4% MFGGBS.

3.10 Effect Of 8% MFGGBS and Varying Percentages of Calcium Chloride & Magnesium Chloride on Atterberg's Limits:

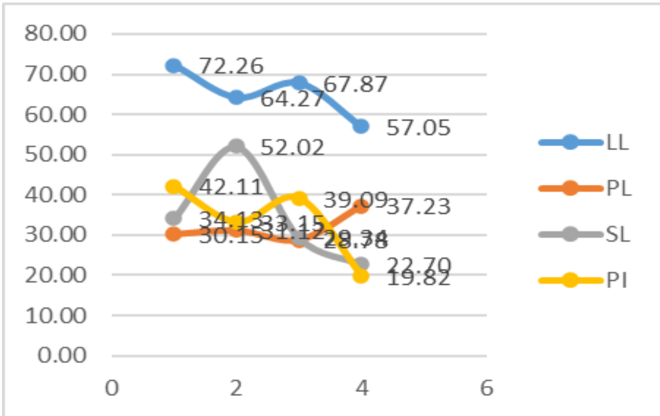

Chart -10: Variation of L.L, P.L, S.L and P.I with 8% MFGGBS + $MgCl_2$ $CaCl_2$ (0.5%, 1%, 1.5%, 2%)

Initially when 8% MFGGBS is added with 0.5% Calcium Chloride and Magnesium Chloride the liquid limit was 72.26% and further addition of Calcium Chloride and Magnesium Chloride gradually to 10% decreased the value of liquid limit to 64.27% by which the soil falls in the category of high degree of expansion. Initially when 4% MFGGBS is added with 0.5% Calcium Chloride and magnesium chloride the plastic limit was 30.15% and further increase in Calcium Chloride and magnesium chloride percentage increased the value to 37.23%. Shrinkage limit was observed to increase gradually from 52.02% to 22.70% (56.38% increase) on addition of 1.5% Calcium chloride and magnesium chloride with 8%MFGGBS. Plasticity Index has reduced from 42.11% to 19.82% (52.94% reduction) which makes the soil to fall from very high degree of expansion category to high degree of expansion (based on P.I).

3.11 Effect of 8% MFGGBS and Varying Percentages of Calcium Chloride & Magnesium Chloride on Compaction Parameters:

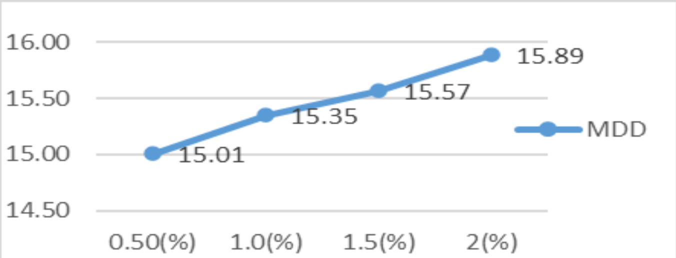

Chart -11: Variation of MDD with 8% MFGGBS + $MgCl_2$ $CaCl_2$ (0.5%, 1%, 1.5%, 2%)

Maximum dry density is observed to increase to 15.89 KN/m³ with addition of Calcium chloride and magnesium chloride 0.5%,1.0%, 1.5% and 2% (marginal increase) keeping 8% MFGGBS as constant.

3.12 Effect Of 8% MFGGBS and Varying Percentages of Calcium Chloride & Magnesium Chloride on Shear Strength Parameters:

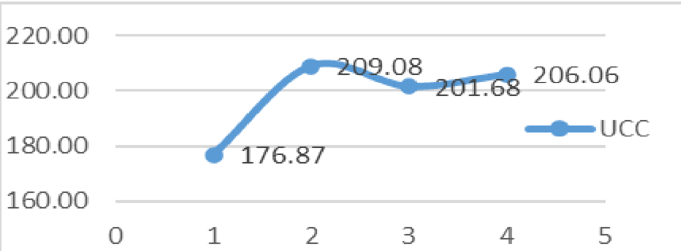

Chart -12: Variation of UCS with 8% MFGGBS + $MgCl_2$ $CaCl_2$ (0.5%, 1%, 1.5%, 2%)

The value of unconfined compressive strength has been gradually increasing from 176.87 KN/m² to 209.08 KN/m² on addition of 1.0% Calcium chloride and magnesium chloride of with 8% MFGGBS but further decreased in Calcium chloride and magnesium chloride and again increase in the UCS value.

3.13 Effect Of 12% MFGGBS and Varying Percentages of Calcium Chloride & Magnesium Chloride on Atterberg's Limits:

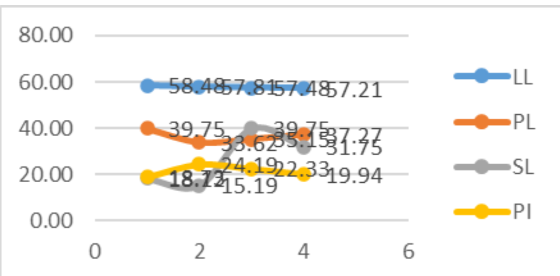

Chart -13: Variation of L.L, P.L, S.L and P.I with 12% MFGGBS + $MgCl_2$ $CaCl_2$ (0.5%, 1%, 1.5%, 2%)

Initially when 12% MFGGBS is added with 0.5% Calcium Chloride and Magnesium Chloride the liquid limit was 58.48% and further addition of Calcium Chloride and Magnesium Chloride gradually to 10% decreased the value of liquid limit to 57.21% by which the soil falls in the category of high degree of expansion. Initially when 12% MFGGBS is added with 0.5% Calcium Chloride and magnesium chloride the plastic limit was 39.75% and further increase in Calcium Chloride and magnesium chloride percentage increased the value to 37.17%. Shrinkage limit was observed to increase gradually from 39.75% to 30.27% (24.30% increase) on addition of 1.5% Calcium chloride and magnesium chloride with 8%MFGGBS. Plasticity Index has reduced from 24.19% to 19.94% (17.74% reduction) which makes the soil to fall from very high degree of expansion category to high degree of expansion (based on P.I).

3.14 Effect of 12% MFGGBS and Varying Percentages of Calcium Chloride & Magnesium Chloride on Compaction Parameters:

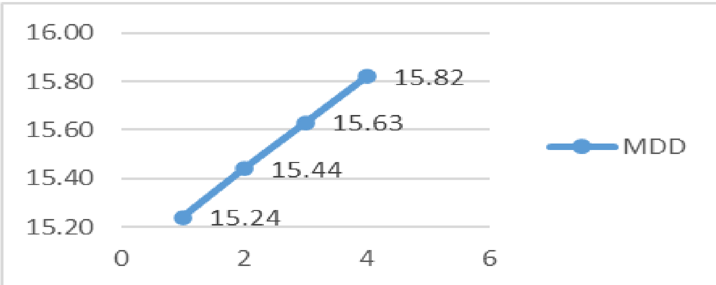

Chart -14: Variation of MDD with 12% MFGGBS + $MgCl_2$ $CaCl_2$ (0.5%, 1%, 1.5%, 2%)

Maximum dry density is observed to increase to 15.82 KN/m³ with addition of Calcium chloride and magnesium chloride 0.5%,1.0%, 1.5% and 2% (marginal increase) keeping 12% MFGGBS as constant.

3.15 Effect Of 12% MFGGBS and Varying Percentages of Calcium Chloride & Magnesium Chloride on Shear Strength Parameters:

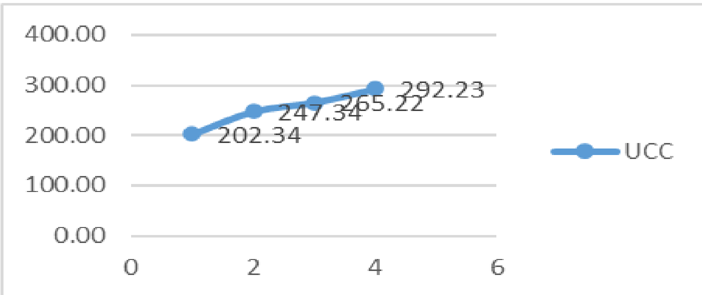

Chart -15: Variation of UCS with 12% MFGGBS + $MgCl_2$ $CaCl_2$ (0.5%, 1%, 1.5%, 2%)

The value of unconfined compressive strength has been gradually increasing from 202.34 KN/m² to 292.23 KN/m² on addition of 2% Calcium chloride and magnesium chloride of with 12% MFGGBS.

4. CONCLUSIONS

Among all the test results obtained, the combination with 2% Calcium chloride, Magnesium chloride and 8% MFGGBS has gained importance which has been discussed below:

- The specific gravity of this combination has been increased from 2.47 to 2.93.
- According to the Indian standards of L.L, the above combination gives 57.05% L.L (21.13% reduction) which falls in the category of high compressibility i.e. 35-50.
- When compared with S.L, this combination has a S.L of 52.02% (70.08% increase) which makes it to fall in the category of low degree of expansion (>13).
- This combination has reduced FSI by 60% to an FSI of 20% which makes the soil to fall in the category of low level of expansion (<50).
- This combination had gained an MDD of 15.89 KN/cm^3 which is very marginal to the MDD of soil sample (15.29KN/cm$^{3)}$, hence it is ok, and OMC has been marginally decreased.

This combination gives highest UCS among other test results i.e.292. 23 KN/m^2

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