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Modification of Engineering Properties of Clayey Soil by Addition of Mine Waste

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Abstract: ***The potential of using iron ore mine waste with an highly compressible clayey soil soil from North Karnataka, India, is investigated in this study. Mining activities lead to the production of waste materials during their extraction and processing stages. The waste maybe in the form of an overburden, waste Rock, Mine Water, or Tailings, depending on the geology, type of processing technology used and the resources mined. The lack of storage space has also been a major concern for the mineral producing agencies, thus paving ways for its better utilization in various construction processes. The collected mine waste was added to expansive soil in different percentages and the mix was tested for Atterberg limits, compaction characteristics, Unconfined compressive strength and California bearing Ratio. It was found that the liquid limit and plasticity index of the soil reduced with addition of mine waste while strength improved. Based on test results of maximum dry density and unconfined compressive strength, a mix of 40% mine waste with 60% expansive clayey soil is recommended for low cost roads. Blending mine waste with expansive soil paves way for sustainable construction besides economic benefits***

Keywords: ***Clayey soil, Black Cotton soil, Mine waste, Expansive soil, CBR, UCC, Soil stabilization, Rural roads***

I. INTRODUCTION

Mining activities has a prime role in contributing towards the economical growth of the country. The GDP contribution of Mining activities ranges from 2.2% to 2.5% which is 10% to 11% of the total contribution from industrial sector [1]. Mining has proved to be one of the key factors for the development of the civilization. The total production of minerals through mining is 17.43 billion metric tons. India has proved to be the major source for mining industry. U.S Geological Survey states the position of India as 4th in the production of Iron ore [8 Karnataka has the second highest Iron Ore reserves in India. The production of Iron Ore Mines in India is anticipated to be 210 MT in the Fiscal Year 2018 in comparison with 192 MT in the fiscal year 2017 [7].

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As per the report of Indian commodity Exchange Limited and Centre of Environment and Science, Karnataka contributes about 41% of the total reserves in the country. The extraction of minerals done by mining leads to the formation of waste materials. These waste generated are the largest waste produced in excess to the obtained minerals. The stripping ratio generally ranges from 2:1 to 6:1 which indicates the production of Mine Waste is 2 to 6 times more than the mineral obtained [3].

Black Cotton Soil projects its volume change behavior upon variation in moisture content. The presence of Montmorillonite mineral in the soil leads to high plasticity, compressibility, swelling, and low strength characteristics. A road constructed on expansive soil leads to failure of pavement layers thus necessitating maintenance more frequently leading to increase in maintenance cost.

There are around 23 small and large scale industries in the vicinity of Bellary district. The forest area was reduced to 38,000 hectares from 77,200 hectares due to mining activities that involves the land used for the storage of mine wastes.

Hence the study on utilization of Mine waste for the construction of Highway Pavement gains prime importance for improvement of sub-grade strength and effective waste management to reduce the environmental impacts of the area surrounded by mining activities.

II. MATERIALS

2.1 Soil

The representative soil used for the study was procured from Yarikoppa village, Dharwad district, North Karnataka, India. The index properties and compaction characteristics were determined as per IS 2720 .The physical and chemical properties of soil is shown in Table 1 and Table 3 respectively.

The soil is classified as A-7-5 as per HRB classification and as high compressible clay CH as per IS classification. The unconfined compressive strength was 162.3kPa and soaked CBR value was found to be 2.3%. The soil is expansive in nature with a low CBR value.

2.2 Mine waste: Iron Ore Mine waste was procured from Venkatagiri Iron Ore Mines, Sandur Taluk, Bellary district.

The physical and chemical properties of mine waste are shown in Table 2 and Table 3. Mine waste exhibited a high specific gravity of 3.08

Expansive soil was partially replaced by mine waste in various proportions and engineering properties of the mix were determined.

Table 1: Engineering properties of soil

Sl No	Property	BC soil
1	**GrainSize distribution** Sand Silt Clay	 14% 42% 44%
2	Specific Gravity	2.66
3	Liquid Limit Plastic Limit Plasticity Index	55.6% 27.6% 28%
4	Free Swell Index	50%
5	**Soil Classification** AASHTO IS	 A-7-5 CH
6	**Heavy compaction** Maximum dry unit weight Optimum Moisture Content **Light compaction** Maximum dry unit weight Optimum Moisture Content	 16.57 kN/m^3 19.8% 16.38 kN/m^3 21.5%
7	California Bearing Ratio	2.16%
8	Unconfined Compressive Strength	162.3kPa

Table 2: Engineering properties of Mine Waste

Sl No	Property	Mine waste
1	Sand Silt Clay	21.31% 14.20% 64.09%
2	Specific Gravity	3.08

Table 3: Chemical properties of Materials

Parameter	Soil	Mine Waste
SiO_2	23.60%	35.89%
Al_2O_3	18.49%	17.01%
Fe_2O_3	-----	2.68%
CaO	29.27%	-----
MgO	4.62%	1.37%
CO_2	23.99%	43.04%

III. EXPERIMENTAL STUDIES

3.1 Sample Preparation

Untreated soil specimens were prepared by mixing known quantity of oven dried soil with required quantity of water.

Mine waste finer than 4.75 mm was oven dried and mixed with BC soil at the partial replacement rate of 10%, 20%, 30% and 40% of soil and tested for specific gravity Atterberg limits, compaction characteristics and CBR.

The soil mine waste mixes for Unconfined Compressive Strength test and CBR test were prepared at their respective maximum dry characteristics and optimum moisture contents. CBR test was performed on samples soaked for 4 days before testing.

In order to examine the effect of curing of soil- mine waste samples , unconfined compressive strength test was conducted for mixes cured for 1, 7 and 28 days.

Three specimens were prepared for each test and average value was determined.

IV. RESULTS AND DISCUSSIONS

4.1 Specific Gravity

The specific gravity tests were conducted for soil and iron ore mine waste mixes. The average value of three trials is indicated in **Table 4**. The results indicate increase in specific gravity value of the soil due to mine waste content. The increase is attributed to the presence of iron content in mine waste.

Table 4: Variation of Specific Gravity with Mine Waste content

Soil: Mine waste	Specific gravity
100: 0	2.66
90 : 10	2.69
80: 20	2.71
70: 30	2.75
60: 40	2.80
50: 50	2.88
0: 100	3.08

4.1 Plasticity Characteristics

Liquid limit and plastic limit tests on soil-Mine waste mixes was conducted in order to understand the effect of mine waste on plasticity characteristics of soil.

The liquid limit and plasticity index reduced with increase in proportion of mine waste in mix.

The results are shown in **Fig 4.1**.

The Liquid limit reduced from 55.6% to 38.4% and Plasticity Index values were reduced from 28% to 22% for 60:40 soil mine waste mix. The reduction in consistency limits were found mainly due to the non-plastic behaviour of mine waste.

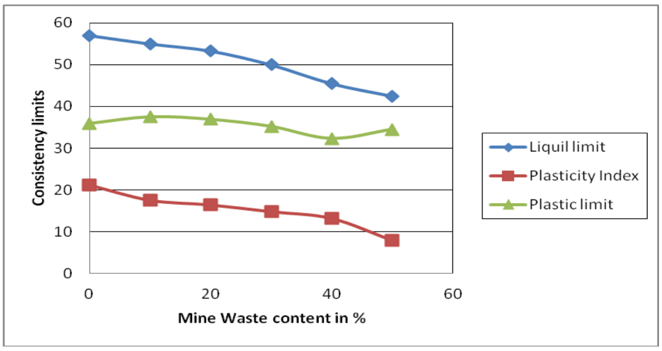

Fig 4.1: Effect of mine waste on plasticity characteristics

4.2: Compaction Characteristics:

Modified proctor compaction tests were conducted on soil mine waste mixes. **Fig 4.2** shows the variation of Maximum Dry Unit Weight with Mine Waste Content.

The maximum dry unit weight of untreated soil was 16.57kN/m^3. Upon replacement with various proportions of mine waste content, the maximum dry unit weight of the mix increased. However, a peak value of 20kN/m^3 was observed for 40% mine waste content.

The optimum moisture content (OMC) of untreated soil was 19.8%. **Fig 4.3** shows the variation of optimum moisture content with partial replacement of mine waste content.

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Upon replacement of soil with different mine waste content, OMC reduced. However, 60:40 mix exhibited least value of optimum moisture content.
For a subgrade, the desirable maximum dry unit weight is 17.5 kN/m^3 as per MORT&H. The mix 60:40 satisfied the criteria.

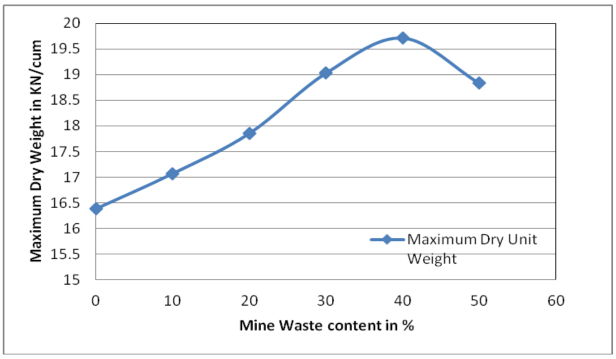

Fig: 4.2 Maximum Dry Unit Weight of soil mine waste mix

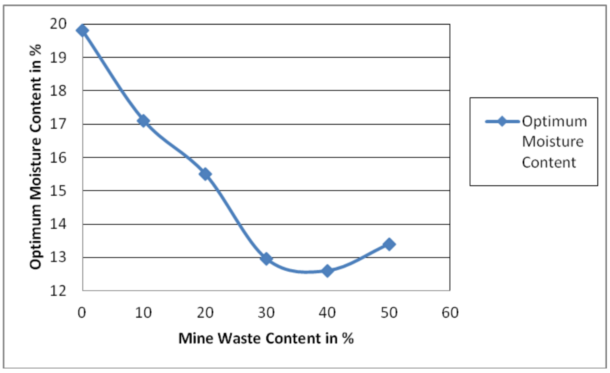

Fig 4.3: Effect of mine waste on optimum moisture content of the mix

4.3: Unconfined Compressive Strength

The unconfined compressive strength (UCS) test for soil mine waste mixes were conducted as per IS 2720 part X. From **Fig 4.4** it is observed that the zero day UCS increases with increase in mine waste content up to 40% in the soil. Upon further addition of mine waste, a decrease in compressive strength was observed. Hence 60:40 mix was considered for further studies.

Effect of curing: UCS samples of 60:40 mix were prepared and cured as per specified procedure for 1day,7days and 28 days and tested. Fig 4.5 shows the variation of UCS with curing period for 60:40 mix.

It is seen from **Fig 4.5** that the UCS increases with increase in curing period. The strength increased from 394 KPa to 590 KPa after 28 days of curing indicating 49% rise in the strength. However, IRC–SP:72 specifies UCS of 7day curing.

The 7 day strength was found to increase by 40%. This shows that the compressive strength of the soil mine waste mix increases with curing time.

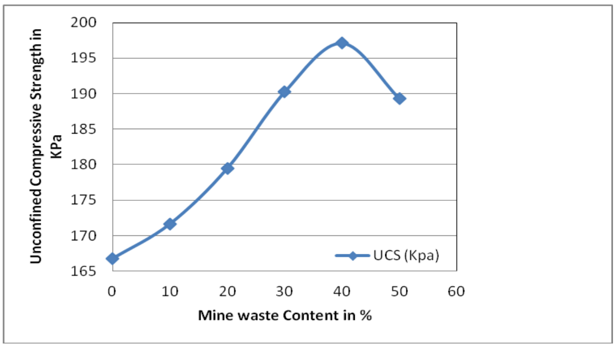

Fig 4.4: Variation of Unconfined Compressive Strength of soil- mine waste mix

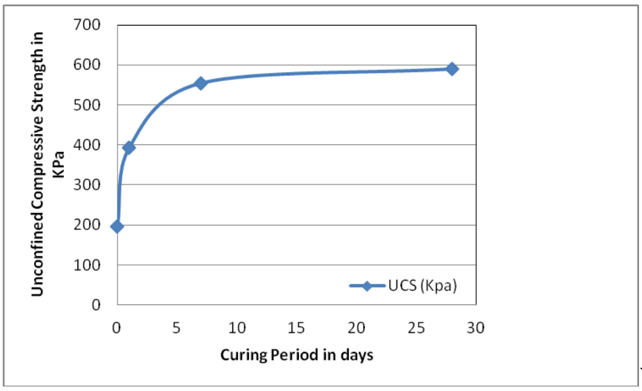

Fig 4.5: Variation of Unconfined Compressive Strength of 60:40 mix upon curing

4.4: California Bearing Ratio (CBR):

California Bearing Ratio test was conducted on soil and mine waste mixes under soaked condition. The preparation and soaking of samples were conducted in accordance with IS 2720 Part XVI.

Substantial increase in CBR value was observed due to the addition of mine waste. Untreated soil exhibited a CBR of 2.3%. The replacement of soil with 40% of mine waste resulted in increase in CBR value to 5.6%. **Table 5** and **Fig 4.6** indicates results of the CBR test on untreated soil and soil mine waste mix.

Table 5: CBR value of soil and mine waste mix

BC soil: MW	Soaked CBR
100 : 0	2.3%
80 : 20	3.2%
70: 30	3.9%
60: 40	5.6%
50: 50	5.2%

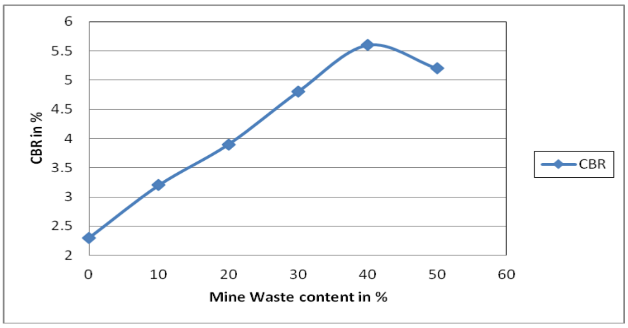

Fig 4.6: Variation of CBR with Mine Waste Content.

As per IRC SP-72 [10], if the subgrade is to be constructed for rural roads, then CBR of 5.6% is considered as a fair quality subgrade. A capping layer of 10cm thick with CBR of 10% needs to be provided above the subgrade. Hence the 60:40 mix of the present study can be used as subgrade with capping layer of 100mm.

However, if the subgrade is constructed for other roads with heavy traffic, the minimum CBR required is 8% as per IRC 37. Then the 60:40 soil mix in the present study needs to be modified by suitable means by an additional additive.

4.5: Micrographs

To study the microstructure of the soil and mine waste, Scanning electron microscopy was performed. The microfabric of untreated soil at 500x magnification has dense clay matrix without aggregation. The SEM of the soil is shown in **Fig 4.7** and that of mine waste in **Fig 4.8**.

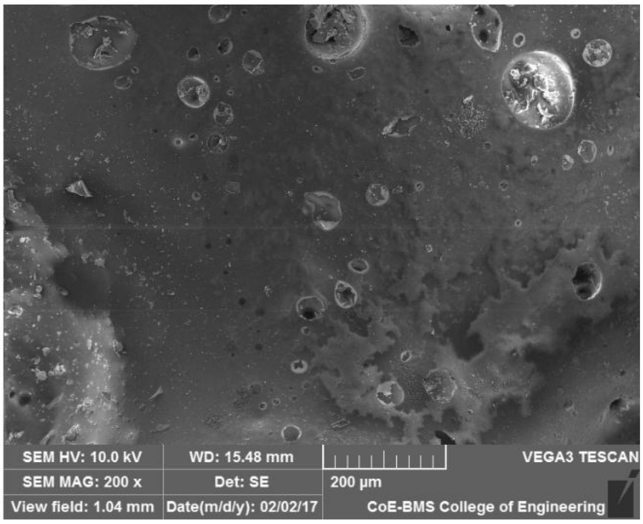

Fig 4.7: Scanning Electron Microscopy of BC soil at 500X

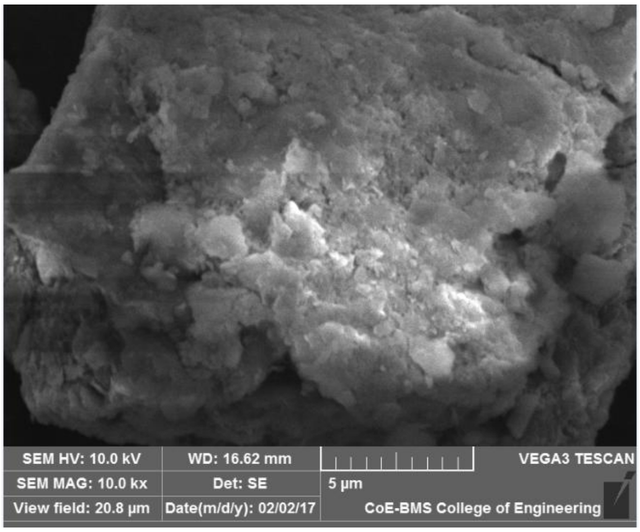

Fig 4.8: Scanning Electron Microscopy of Mine Waste

V. CONCLUSION:

Based on experimental studies the following conclusions are drawn:

1. Addition of Mine waste to soil increases its specific gravity and dry density. The increase is attributed to presence of iron content.
2. A reduction in plasticity characteristics of soil is observed upon addition of mine waste due to the increase in percentage of non- plastic material in the mix.
3. The Maximum dry density of soil Mine Waste mix increases indicating requirement of higher compactive effort.
4. A soil to mine waste ratio of 60:40 was optimised based on density and strength of the mixes.
5. The unconfined compressive strength of 60:40 mix was found to be 394kPa, 555kPa and 590kPa for 1, 7 and 28 days cured specimens respectively. This indicates that occurrence of continous of chemical reaction in the mix with increase in time leads to strength gain .
6. The four days soaked CBR value of untreated soil was found to be 2.3% which increased to 5.6% for 60:40 mix.
7. The 60:40 ratio of soil and mine waste can be used as subgrade for rural roads with a capping layer. However for other roads with heavy traffic, the mix needs to be strengthened with additional additive to increase the CBR.
8. The two materials, soil and iron ore mine waste used in present study are located close by in North Karnataka region. Hence using iron ore mine waste seems economical for that region and solves the environmental problem of waste disposal and storage.

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