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An Investigation to Study the Moisture Dependency of Ground Enhancement Compound

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***Abstract*—**Lightning protection consists of three main parts; mainly air termination system, down conductor, and earth termination system. Earth termination system is the most important part as earth is the sink and source of charges. Therefore, even when the charges are captured and delivered to the ground, and an easy path is not provided to the charges, earth termination system would lead to problems. Soil has significantly different resistivities ranging from 10 Ωm for wet organic soil to 10000 Ωm for bedrock. Different methods have been discussed and used conventionally such as deep-ground-well method and altering the length of the rod. Those methods are not considered economical. Therefore, it was a general practice to use charcoal along with salt to reduce the soil resistivity. Bentonite is worldwide acceptable material, that had led our interest towards study of bentonite at first. It was concluded that bentonite is a clay which is non-corrosive, environment friendly. Whereas bentonite is suitable only when there is moisture present in the soil, as in the absence of moisture, cracks will appear on the surface which will provide an open passage to the air, resulting into increase in the resistivity. Furthermore, bentonite without moisture does not have enough bonding property, moisture retention, conductivity, and non-leachability. Therefore, bentonite was used along with the other backfill material to overcome the dependency of bentonite on moisture. Different experiments were performed to get the best ratio of bentonite and carbon backfill. It was concluded that properties will highly depend on the quantity of bentonite and carbon-based backfill material.

***Keywords*—**Backfill material, bentonite, conducting soil, grounding material, low resistivity.

I. Introduction

LIGHTNING protection system consists of three important parts; air termination system, down conductors, and earth termination system. The most important part is the earth termination system, where our earth is a natural object and it is a source and sink of charges [1]. Soils, by nature, are non-homogeneous media, and anisotropic in general. It is well known that heterogeneity increases the soil resistance, which makes the whole process difficult [2]. Therefore, it is another important reason to replace surrounding soil of earth rod with homogenous compound. A copper rod is placed in the earth surrounded by ground enhancing compound as shown in Fig. 1 [3]. This will increase the grounding electrode diameter, which will eventually reduce the scattered flow resistance and will lead to quicker electrical current dissipation during a lightning strike [4].

Soil resistivity is highly influenced by environmental factors, such as moisture content, temperature variations, and pore size of grains [2]. Air pockets present in the soil will work as an insulator and will influence the easy passage of the charges in case of lightning.

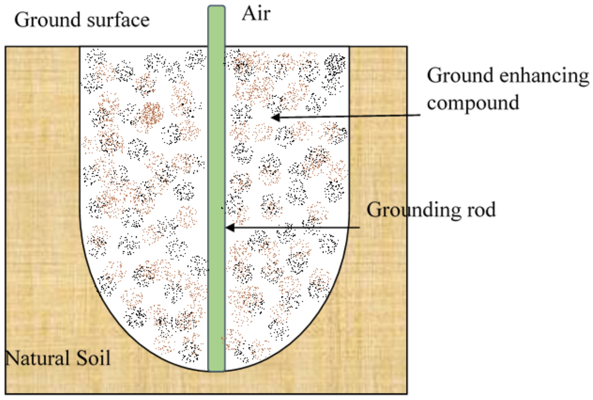

Fig. 1 Representation of earth termination system

Different earth enhancement compounds have been known worldwide as a replacement of soil for supporting the earth termination system [5]. There are many different materials known to use as a replacement of soil such as, bentonite, graphite, charcoal, and different types of salts [6]. Therefore, variation in the soil type may affect the grounding system drastically. The soil could be extremely acidic or alkaline in nature, which may lead to degradation of earthing system. High alkalinity or acidity of soil will increase the probability of corrosion and hence overall degradation of efficiency of lightning protection system [7]. Bentonite is natural clay, which has capacity to absorb the water 5x of its weight and swell as much as 13X of its original weight, which makes the bentonite highly effective for lightning protection [4], [5]. Bentonite is known to be used without any additional mixture. Therefore, a detailed investigation was done to understand the dependency of bentonite on moisture in controlled environment.

II. Experimental Work

A. Primary Material Used

1. Bentonite (Industrial Grade)
2. Carbon Powder (Industrial grade)
3. Tap Water

B. Experimental Procedure

The materials were mixed in a planetary mixture in order to

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get a homogeneous mixture. Tap water was used to mix the material and poured in the molds in three parts. All the steps have been given in the block diagram in Fig. 2.

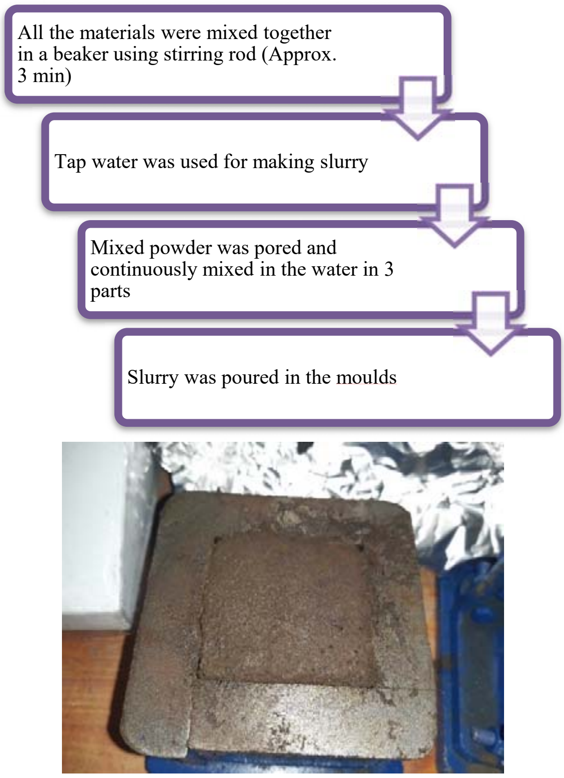

Fig. 2 Step wise process of experimental procedure

C. Equipment Used

1. Resistivity meter
2. Millar box
3. Hot air oven
4. Flow table
5. Molds cubical (5 cm dia)
6. Planetary mixture

III. Results and Discussion

A. Characterization of Raw Materials

Characterization of bentonite (B) and carbon powder was done in-house. A sample of the B-clay was as shown in Fig. 3.

Fig. 3 Sample of bentonite clay

Physical properties have been compiled Table I.

TABLE I
PROPERTIES OF B-CLAY

S. No.	Property	Measured value
1	Color	Yellow
2	Odor	Odorless
3	Density, kg/m^3	1600
4	pH value	7.5

Carbon powder was used in order to make the overall mix conductive (Fig. 4). It was observed that industrial grade bentonite clay was not conducting. The resistivity testing was done using a fluke resistivity meter (calibrated) along with a standard millar box attached with it. Therefore, it was concluded that bentonite is not conductive at dry state.

B. Resistivity Measurement

A calibrated resistivity meter was used along with the standard rectangular millar box to analyze the resistivity of bentonite clay at dry state. Millar box contains 4 electrodes, out of which, two are connected with the current probe and other two are with potential probe of resistivity meter. There material should be conductive in order to measure the potential between two electrodes while providing the current from two ends.

It was noted that there was no value detected on resistivity meter which concludes that clay particles are not providing a path and hence are not conductive. Therefore, it was decided to use the conductive carbon particles along with the B-clay. The measured and observed physical properties are listed Table II. The resistivity of 0.012 Ωm was measured which shows that the material is conductive.

TABLE II
PROPERTIES OF CARBON POWDER

S. No.	Property	Measured value
1	Color	Black
2	Odor	Odorless
3	Density, kg/m^3	1250
4	Resistivity, Ωm	0.012
5	pH value	7.15

Fig. 4 Photographic image of carbon powder

C. Final Resistivity of Earthing Material

Final earth enhancement compound had the overall resistivity of 0.12 Ωm with equal quantity of bentonite and carbon powder. Therefore, the criterion of resistivity was fulfilled as per IEC 62561-part 7.

D. Water to Solid Ratio

As discussed in the experimental work section, tap water was used for all the experimentation considering practical aspect of using backfill whereas pH of water was in the range of 7-8. Earth enhancement compound was synthesized and analyzed after making the sample with tap water. Different properties were observed for the prepared slurry at water to solid ratio of 1.

E. Soil Compacting Nature of Backfill

Flow property was measured as it is an important parameter for defining compactness of mortar in soil or actual environmental conditions. It was noticed that the composition was highly flowable at water to solid ratio of 1. Flow percentage was measured as per Indian standard, IS:5512-1983. Flow percentage was 107.5% for the mixed slurry. The result shows that the mortar is highly flowable and have a very good soil compacting property (Fig. 5).

The formula used for measuring flow percentage is:

$$Flow\ \% = \frac{D_{avg} - D_o}{D_o} * 100$$

where D_{avg} = Average base dia, cm, D_o = Original base dia, cm.

Fig. 5 Flow percentage measurement of mortar

F. Water Absorption

Moreover, water absorption property was also measured for 24 hours. The mortar should be able to absorb the moisture before final setting of the mortar. It is well known that absorbed moisture will help in the hydration and long-term strength of the concrete. The backfill materials used are generally mixed with a bonding agent which provides the long-term strength of the concrete.

Cubic samples of mixed material were prepared and dried in the oven until the weight of the samples was constant. Samples were then tested for water absorption. In the water absorption test, the samples were put in the water tray named 'water pond' and samples were allowed to absorb the water for 24 hours. This method was adopted from concrete curing which was used for concrete to cure and gain strength. It was new to observe that sample was crumbled in the water pond which was filled with water as can be observed from Fig. 6. Therefore, we may say that water absorption was 0% as material could not be intact in the water.

Fig. 6 Material crumbled in lab tray filled with water (In-house test)

Samples were not able to set at ambient condition for 3 days. Samples were set after 3 days by absorbing moisture which was present at the time of mixing (w/s = 1). Although some cracks were observed after 3 days. Cracks were analyzed and it was observed that small cracks were there which extended slowly and after 5 days the cracks growth was large as can be observed from Fig. 7. Sudden moisture loss could be one reason for the crack appearance on the surface. This might not be the case for actual environmental conditions where humidity is present which acts as a small reservoir for the backfill whereas cracks are filled with air which is an insulator and will increase the resistivity of the testing sample. Therefore, bentonite is best to use although these little cracks may create the problem in future.

Fig. 7 Cracks observation at the surface of sample

IV. Conclusion

This study was done to analyze the behavior of bentonite along with carbon powder in lab. Bentonite has been used for earthing so far and have been proved as an environment friendly solution based on its environment friendly nature (pH = 7.5). In the absence of moisture, it is mandatory to use other conducting materials such as carbon powder. The resistivity measurement of bentonite clay also concluded that B-clay is highly moisture dependent at dry state. Moisture loss from the samples will lead to development of cracks because of moisture dependency of bentonite. Therefore, while installation it is necessary to create some reservoir in the earth pit itself and do the periodic check for change in the resistivity.

It is suggested that further study to be carried forward in order to overcome the leachable and cracking behavior of samples prepared using B-clay and carbon powder.

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REFERENCES

[1] S. C. Lim, C. Gomes, M. Z. A. A. Kadir, G. Nourirad, and Z. A. Malek, "Behaviour of backfill materials for electrical grounding systems under high voltage conditions," *J. Eng. Sci. Technol.*, vol. 10, no. 6, pp. 811–826, 2015.

[2] M. Kižlo and A. Kanbergs, "The Causes of the Parameters Changes of Soil Resistivity," *Sci. J. Riga Tech. Univ. Power Electr. Eng.*, vol. 25, no. 25, pp. 43–46, 2010, doi: 10.2478/v10144-009-0009-z.

[3] J. F. Tatum, "Ground Electrode Backfill Composition, Anode Bed and Apparatus," 4,786,388, 1988.

[4] A. Azmi, N. A. Ahmad, L. K. Yiew, and Z. Abdul-Malek, "The use of enhancement material in grounding system: A review," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 13, no. 2, pp. 453–460, 2019, doi: 10.11591/ijeecs.v13.i2.pp453-460.

[5] Z. Bin Burhanuddin, C. Gomes, A. Gomes, M. Z. K. Ab Kadir, W. F. Wan Ahmad, and N. Azis, "Characteristics of fulgurite-like structures under HV conditions: Effects on electrical earthing systems," *33rd Int. Conf. Light. Prot. ICLP 2016*, pp. 1–4, 2016, doi: 10.1109/ICLP.2016.7791435.

[6] H. Ş. Arel and E. Aydin, "Effects of Ca-, Mg-, K-, and Na-lignosulfonates on the behavior of fresh concrete," *Constr. Build. Mater.*, vol. 157, no. December, pp. 1084–1091, 2017, doi: 10.1016/j.conbuildmat.2017.09.190.

[7] A. Ghavamian, M. R. Maghami, S. Dehghan, and C. Gomes, "Concerns of corrosive effects with respect to lightning protection systems," *Eng. Fail. Anal.*, vol. 57, no. November, pp. 434–443, 2015, doi: 10.1016/j.engfailanal.2015.08.019.