Experimental Studies on Utilization of Blast Furnace Slag for Cohesionless Soil

Dr. Bhavin G. Buddhdev[1] [0000-1111-2222-3333] and Prof. M. V. Chauhan[2] [1111-2222-3333-4444]

[1] Assistant Professor, Applied Mechanics Department, Vishwakarma Government Engineering College, Chandkheda, Ahmedabad (Gujarat, India)
[2] Assistant Professor, Applied Mechanics Department, Vishwakarma Government Engineering College, Chandkheda, Ahmedabad (Gujarat, India)
bhavin_buddhdev@hotmail.com; mukeshchauhan4809@gmail.com

Abstract. In the present state, utilization of various waste materials in different geotechnical application is increase manifold. All the waste materials are possesses different characteristics depending upon its raw materials and processing techniques. Utilization of these waste materials needs greater concern of its properties and compatibility with parent material. Out of many waste materials available, Blast furnace slag is one of them. Blast furnace slags are by-products of metallurgical processes. It is glassy material, vesicular textures, typically with sand-to-gravel-size particles can be converted into powder form as well as particular desire size particles. In this paper, experimental work has been carried out on cohesionless soil with utilization of BFS to improve its properties for various geotechnical applications. Based on the literature review, it was evident that no much experimental work had been done on cohesionless soil as compared to cohesive soils. Therefore attempt has been made to check the effect of utilization of BFS in cohesionless soil with various proportions of BFS mixed with cohesionless soil. Experimental results has indicate positive outcome in terms of soil improvement for cohesionless soil with utilization of BFS. This research is very much useful for utilization of this waste material for soil improvement especially for cohesionless soil with poor characteristics for many geotechnical applications. Utilization of this waste material will also solve many environmental issues related to its stockpiling and dumping which ultimately protect the environment.

Keywords: Blast Furnace Slag, Cohesionless soil, Waste Materials, Soil improvement.

1 Introduction

Research into new and innovative uses of waste materials is need of days in the era of sustainability. Utilization of waste materials can be decided based on factors like availability, technical suitability, environment impact and economic benefits. Presently, along with series of waste materials production, most of the countries including India are producing tons of blast furnace slag (BFS) which is the by-product of steel industries. This unutilized BFS is stock piled in the steel plants, and eventually land filled at slag disposal sites. Since the current methods of stockpiling and land filling are not sustainable, disposal of BFS has become a significant concern both to slag processor companies and to environmental agencies. There was very limited information on the engineering properties of BFS in the literature, so research that focuses on engineering properties of blast furnace slag was scarce. BFS is the byproduct of metallurgical operations, typically containing gangue from the metal ore, flux material, and unburned fuel constituents. As a product of calcinated flux stone and the alumina and silica phases present in iron ore, the four major oxide phases present in BFS are CaO, SiO_2, Al_2O_3, and MgO. These oxides account for approximately 95 percent of the BFS composition "(Hammerling, D. M. 1999)" [1]. The physical properties of BFS are largely controlled by how it cools and solidifies. The color of BFS coarse aggregate usually varies from light to dark gray, depending on chemical composition. The void structure of the BFS heavily influences the physical properties, including the bulk specific gravity and the absorption "(Lewis, D. W. 1982)" [2]. Based on the chemical and physical properties, BFS can be converted into any desire size fraction to make it suitable for various geotechnical applications. Utilization of BFS in geotechnical application till now is mainly for soil improvement of expansive soil like black cotton soil as well as in road construction as aggregate in flexible and rigid pavements. Some of the cases, BFS is utilized as improvement in sub base materials for road construction has been noted. Still utilization of BFS with cohesionless soil based on site specific condition as well as application in foundation of various structures is missing in literature. Based on the availability of BFS in national context, the proper guidelines at the production unit as well as collection and convergence in required form is not establish as compared with global context. In this paper, extensive experimental program was carried to evaluate the properties of virgin soil as well as BFS. Based on the characterization results, effect of BFS in cohesionless soil was studies by replacing BFS with virgin soil in proportion of 15% and 25% by weight. The selection of percentage proportions of BFS with virgin soil was based on the literature as well as to know the proper effect of BFS with wide range of difference in percentage. This mixture of BFS and cohesionless soil has been evaluated for OMC-MDD, CBR and shear strength parameters. The results of this selected parameters for both the proportions indicated the better improvement with BFS in the virgin soil. This experimental study opens the new area of utilization of BFS especially with cohesionless soil in many geotechnical applications. This study is an attempt to understand the effectiveness of utilization of BFS in certain area which provide greater economy with saving of precious nature resources.

2 Literature Review

Many researchers had put their sincere efforts to use the BFS coming out from steel processing units in various geotechnical applications. Many research papers were reviewed related to cohesionless soil with BFS and other waste materials. Many of them were about BFS was utilized for geotechnical applications like earth-fill, embankment, sub-base and base course for pavement etc. The following paragraph illustrates the development in the utilization of BFS with cohesionless soil as well as scenario for different geotechnical applications.

"According to Hendrik G. (2002)" slag has been used for construction purposes-especially road metal since Roman times. The dramatic expansion in Europe of iron and steel production associated with the industrial Revolution led to a commensurate increase in slag production. By the early 19th century, slag output was rapidly outpacing consume\piton and there was an alarming growth of unattractive slag heaps on valuable industrial land. By the mid-19th century, research had demonstrated a number of new uses for slag, particularly as an aggregate for concrete and as a cementations material in its own right. Consumption remained relatively modest until the 20th century, when a major new use-in asphalt blend for road paving-was developed and became popular in step with demand for smooth roads by the growing automobile owning public. This use, together with the rapid growth of concrete usage worldwide, led to the consumption of most existing slag heaps and a current consumption roughly apace with new slag production. The utilization of slag, therefore, is one of the great, yet relatively unsung, stories of recycling. Research is ongoing to expand and refine the uses of slag. Slag is properly recognized as a valuable coproduce of iron-and steelmaking, not a waste product [3].

BFS is obtained during the manufacture of iron and steel and possesses inherent hydrated properties. It was utilized for making different types of construction materials "(www.Academicjournals.org/ijps/pdf/.../ Safiuddin %20et%20al.pdf)" [4]. "According to Emery (1980)", loose dry unit weight values for palletized BFS range from 8.2 to10.4 kN/m^3. BFS is glassy material, typically with sand-to-gravel-size particles [5]. Most of the studies in the literature focus mainly on the chemical composition and mineralogy of BFS to assess its cementitious properties rather than its mechanical properties. "As per Noureldin et al. (1990)" reported on some of the engineering properties of blast furnace slag [6].

Maximum dry density of soil increases while plasticity characteristics gradually decreases with increase in slag content and thus the CBR value of soil increases and therefore increases soil strength "(Biradar et al., 2014; Rao et al. 2014; Singh and Ali 2014)" [7]. Slag content in natural soil increases its workability by reducing its liquid limit and thus its plasticity "(Rao et al., 2014)" [8]. It was recommended "(Chaubey and Ali Jawaid, 2016)" for natural soil with 25% slag as an optimum stabilization ratio for soil and can be used for sub grade as well as in pavement [9]. "Poh et al. (2006)" showed that there is potential in utilizing BOF slag fines in stabilization of fine-grained soils when activators are used [10].

Dayalan J (2016) studied on the stabilization of soil with BFS and Fly Ash. Soil stabilization has become the major issue in construction engineering and the researches regarding the effectiveness of using industrial wastes as a stabilizer are rapidly increasing. This study briefly describes the suitability of the local fly ash and BFS to be used in the local construction industry in a way to minimize the amount of waste to be disposed to the environment causing environmental pollution. In this study, different amount of fly ash and BFS are added separately i.e. 5, 10, 15 and 20% by dry weight of soil are used to study the stabilization of soil. The performance of stabilized soil are evaluated using physical and strength performance tests like specific gravity, Atterberg's limits, standard proctor test and California Bearing Ratio (CBR) test at optimum moisture content. From the results, it was found that optimum value of fly ash is 15% and BFS is 20% for stabilization of given soil based on CBR value determined [11].

Tarkeshwar Pramanik et al (2016) studied the behavior of soil for sub grade by using marble dust and BFS. In this paper, sandy clayey soil was stabilized using the combination of marble dust and BFS in different proportion (i.e.0%+0%, 5%+5%, 10%+10%, 15%+15% & 20%+20%) and characteristic behavior (i.e. OMC, MDD, UCS, CBR & Permeability) of modified soil in the laboratory was studied. The series of test has been conducted in laboratory and it is found that marble dust and BFS (15%+15%) is sufficient to increases the California bearing ratio in unsoaked and soaked condition value up to 195% and 100% approximately [12].

A. Kavaki et al (2016) studied on the reuse of BFS in lime stabilized embankment materials. In this paper, an effective way of utilizing the BFS with lime has been presented for stabilization of road materials. In the study Ankara clay was used for stabilization. Although slag, lime and clay mixtures do not affect optimum water contents of clay significantly, they decrease dry density and smoothes proctor curve. Then, the soil transforms into a rapid structure and the modulus of elasticity increases. When the results of the experiments were evaluated, unconfined compressive strength (UCS) and soaked California Bearing Ratio (CBR) values of the soils have shown significant increases. These increases reach to 46 times in CBR values for Ankara clay compared to natural case in 28 day-cured samples. This stabilization technique is more effective than the lime alone and also the slag will prevent the ettringite formation that occurs in lime stabilization with sulfate rich soils that leads swelling behavior. Finally the slag may turn from a waste material into a valuable product for road construction works with huge volumes even at far away from the steel factories [13].

Ms. Radha Gonawala et al. evaluated Soil and GGFS (10, 15 and 20%), Soil and lime (3, 4, and 5%), Soil and cement (0.5, 1 and 1.5%) for their engineering characteristics by laboratory investigations for embankment construction. Different laboratory tests carried out included: grain size analysis, Atterberg's limit test, Proctor compaction test, CBR test, aggregate impact value test, Abrasion test and moisture absorption test [14].

Akin Musuru (1991) studied the cause of mixing of BFS on the consistency, compaction, characteristics and strength of lateritic soil. It was observed decrease in both the liquid and plastic limit. The compaction, cohesion and CBR improved with increasing BFS up to 10%, then if add 15% of BFS decrease the strength. The angle of internal friction decreased with increase in BFS [15].

Based on literature review, experimental program was decided to understand the effect of BFS when mix with cohesionless soil in different proportions to evaluate certain parameters. Literature review suggested that very less experimental work was done in past considering only BFS as substitute material with cohesionless soil.

3 Experimental Work

3.1 Introduction

In the present study, an exhaustive experimental programme was conducted to evaluate effect of the blast furnace slag available locally when it is used as construction material in various proportions to the soil in different geotechnical applications. The characterization of blast furnace slag is done which is locally available. Some soil samples (representative of both coarse & fine grained) were adopted for the study. Geotechnical parameters like OMC-MDD, CBR and shear strength parameters values are studied for soil sample selected by adding various percentage of slag mix with it. Details of material used, processing test procedure adopted are described.

3.2 Material Used

Blast Furnace Slag: BFS obtained from industrial area of Rajkot city, Gujarat, India (Refer photograph – 1) of Size-4.75 mm down up to 150micron having gradation shown in fig.1 has been selected. Table 1 shows the chemical properties of BFS used in the study [16]. The characterization of BFS was done for properties necessary for the experimentation and shown in Table 2. BFS is a waste materials mainly collected from steel processing units. It is consisting of some iron fractions also may leads to some higher value of specific gravity. It cannot be directly comparable with soil.

Photograph 1. Blast furnace slag sample

Fig. 1. Gradation of Blast Furnace Slag [17]

Table 1. Chemical Properties of Blast Furnace Slag.

Chemical Properties of BFS in %	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	SO_3
	26.5	34.0	17.25	7.0	18.25	0.5

Cohesionless soil: Soil samples are collected from Riverfront area of Sabarmati River in Ahmedabad city for experiment purpose so that effect of slag for soil stabilization purposes can be worked out. Gradation of the soil sample considering size-4.75 mm down up to 150micron is done and shown in fig.2. More than 90% is coarse grained soil retained in 75 micron sieve, while fine grained fraction are around 5 to 10%. The characterization of collected soil sample was done for properties necessary for the experimentation and shown in Table 2.

Fig. 2. Gradation of Soil [17]

Table 2. Characterization of blast furnace slag & selected soil [17,18,19].

Sr. No.	Description	Virgin Soil	Blast Furnace Slag
1.	Classification as per IS	SM-SC	SM-SP
2.	Water Content	11.25	15.11
3.	Specific Gravity	2.66	2.72
4.	Liquid Limit	20.20	NP
5.	Plastic Limit	14.28	-----

3.3 Experimental Test Procedure

All the experiments are performing as per the procedure and provision laid down in relevant IS codes.

4 Results and Discussions

The major aim to perform the experiment on BFS along with Cohesionless soil is to evalute the feasability of this waste material with soil. The experimental outcome may lead to an extent for utilization of this BFS with soils.

BFS and representative soil samples were selected and taken for purposes of experimentation. The aim for soil improvement is to stengthen the virgin soil properties and enhance the soil properties to desired level. Both slag and selected soil are characterized for different geotechnical parameters(Refer Table 2). OMC-MDD value of virgin soil, BFS is evalueted with standard proctor test. In this work, effect of BFS with soil under compaction behavior need to be evaluated, that is why to start with first standard Proctor test was selected. Yes, one can perform the same with modified proctor test also. Based on the OMC-MDD value obtained, it is decided to add 15% and 25% of BFS by weight to the soil. The appropriate change in the OMC-MDD is shown in the Fig. 3. OMC-MDD value of mixture of soil and BFS shown increased in maximum dry density as compare with virgin soil. The percentage increase in maximum dry density was not much as increase in percentage of BFS from 15% to 25%. This behaviours in OMC-MDD witness that thier was no significant effent of BFS with cohesionless soil. Still one can try for higher percentage of BFS replacement, but this trends indicative of not much improvement. California bearing ratio (CBR value) is considered as a most important geotechnical parameter for the pavement design. Design of pavement is unsafe and uneconomical on a poor sub base. To strengthen the poor sub base certain amount of slag may be utilized to improve overall quality of strata. On a selected soil, BFS is added in amount of 15% and 25% by weight to the soil. The CBR test is done for both soaked and unsoaked condition. The details of results are shown in Table 3. CBR value (both soaked and unsoaked) was increased with mixture of BFS with virgin soil. The MDD value for 15% and 25% BFS + Soil having very small marginal difference, while both unsoaked and soaked CBR values evaluated from experimentation is higher may be due to higher resistance develop in presence of BFS. CBR value was also increased substantially with increased percentage of BFS from 15% to 25%. This increased value was indicative that there was very positive impact of BFS on CBR value with cohesionless soil. Shear strength parameters were evaluated by conducting direct shear test on virgin soil, BFS as well as mixture of BFS and virgin soil in proportions of 15% and 25% by the weight to the soil. Based on the test carried out cohesion (C) and angle of internal friction (ϕ) were evaluate as shown in Table 4. The angle of internal friction increases as the increased in the BFS percentage with virgin soil. This increased may be due to the granular form of BFS particle with virgin soil properties. As the BFS is non plastic granular material, no cohesion occurred during test. These effects lead to the decreased in the cohesion value when it is mixed with virgin soil.

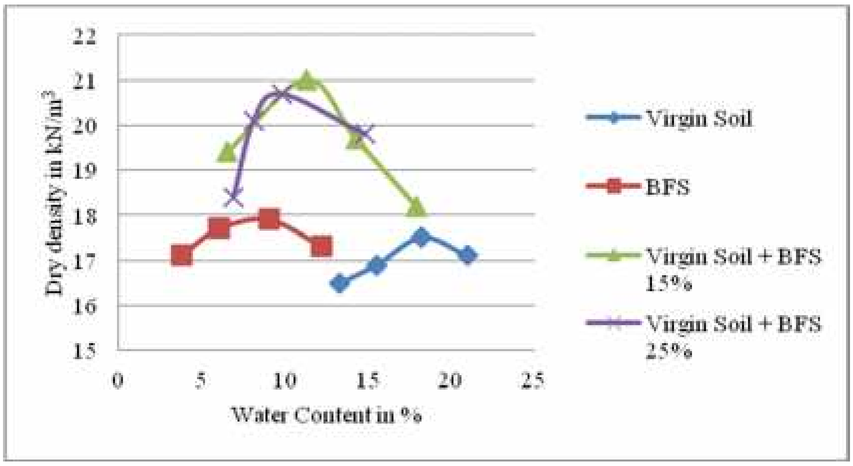

Fig. 3. Summary of OMC-MDD for Virgin Soil and BFS [20]

Table 3. Summary of CBR for Virgin Soil and BFS [21].

Sr. No.	Description	Unsoaked CBR	Soaked CBR

1.	Virgin Soil	7.30	5.70
2.	BFS	19.90	16.20
3.	15% BFS Proportion	10.12	8.60
4.	25% BFS Proportion	13.10	11.70

Table 4. Summary of Shear Strength Parameter for Virgin Soil and BFS [22].

Sr. No.	Description	Cohesion (C) kN/m^2	Angle of Internal Friction (ϕ°)
1.	Virgin Soil	12	28°
2.	BFS	----	35°
3.	15% BFS Proportion	11	32°
4.	25% BFS Proportion	9	33°

5 Conclusions

An experimental work is carried out to study use of BFS as soil improvement and used to enhance the overall quality of related geotechnical materials, by saving the natural resources which is day by day become scared. The primary characterization indicates the BFS have an enough potential to use as a geo material for different geotechnical application. Further, the test results of OMC-MDD, CBR and shear strength parameters are indication of improvement in soil property selected at very primary level but at the same time it will propagate for other secondary properties of soil as per the requirement of the projects. Analysis of experimental results showed a good improvement like CBR and angle of internal friction but at the same time OMC-MDD results indicate very little improvement. Pure cohesionless soil mix with properly graded BFS will give more improvement in terms of angle of internal friction as the negative effect due to cohesion not impact on shear strength parameters. Based on above discussion BFS has a good potential to utilize in certain geotechnical application like embankments, roads, pavement construction, fill etc. Furthermore as compare to the other waste material like flyash, bottom ash etc., BFS is underutilized till date. To facilitate and motivate the use of BFS, there is need to develop some crushing units which produced BFS of require size which will available domestically at cheaper rates.

References

1. Hammerling, D. M. 1999. Calcium Sulfide as Blast furnace Slag Used as Concrete Aggregate, M.S. Thesis. Michigan Technological University, Houghton, MI pp. 1-8 (Page 3).
2. Lewis, D. W. 1982. Properties and Uses of Iron and Steel Slags, National Slag Association pp. 1-11.
3. Hendrik G. 2002. SLAG-IRON AND STEEL, U.S. Geological Survey Minerals Yearbook, 2002 pp. 1-24.

4. http://www.academicjournals.org/ijps/pdf/.../Safiuddin%20et%20al.pdf.
5. Emery, J.J. 1980. Palletized Lightweight Slag Aggregate, Proceedings of Concrete International, Concrete Society pp. 1-11.
6. Noureldin, A.S. and McDaniel, R.S. 1990. Evaluation of surface mixtures of steel slag and asphalt, Transportation Research Record 1269, Transportation Research Board, National Research Council, Washington, D.C., pp. 133–149.
7. Biradar, K. B., kumar, A. U. And Satyanarayana, P.V.V. 2014. Influence of Steel Slag and Fly Ash on Strength Properties of Clayey Soil: A Comparative Study, International Journal of Engineering Trends and Technology (IJETT) Volume 14, Number 2, Aug 2014 pp.61-64.
8. Rao et al. 2014. A Laboratory Study on the Effect of Steel Slag for Improving the Properties of Marine Clay for foundation beds, International Journal of Scientific & Engineering Research, Volume 5, Issue 7, July-2014 pp. 253-259.
9. Chaubey, S. and Ali Jawaid, S. M. 2016. Soil stabilization using steel slag, Global Journal for Research Analysis, Volume-5, Issue-1, January -2016.
10. Poh, H.Y., Ghataora, S.G., and Ghazireh, N. 2006. Soil stabilization using basic oxygen steel slag fines, Journal of Materials in Civil Engineering, ASCE, Vol. 18, No .2, pp. 229-240.
11. Dayalan J. "Comparative Study on Stabilization of Soil with Ground Granulated Blast Furnace Slag (GGBS) and Fly Ash", International Research Journal of Engineering and Technology (IRJET)" E-ISSN: 2395-0056 Volume: 03 Issue: 05 | May-2016 www.irjet.net p-ISSN: 2395-0072 pp. 2198-2204.
12. Tarkeshwar Pramanik, "Study the Behaviour of Soil for Sub Grade by using Marble Dust and Ground Granulated Blast Furnace Slag. International Journal of Innovative Research in Science, Engineering and Technology (An ISO 3297: 2007 Certified Organization) Vol. 5, Issue 5, May 2016 pp. 37-41.
13. A. Kavakì "Reuse of Ground Granulated Blast Furnace Slag (GGBFS) in Lime Stabilized Embankment Materials", IACSIT International Journal of Engineering and Technology, Vol. 8, No. 1, February 2016 pp. 11-14.
14. Ms. Radha Gonawala et al. Use of Granular Blast Furnace Slag in Embankment Construction, Recent Advances in Civil Engineering for Global Sustainability (RACEGS-2016) pp: 357 – 361, SVNIT, Surat, Gujarat, India.
15. Akin musuru 1991,"Potential Beneficial steel slag wastes for civil Engineering Purposes", Resources Conservation and Recycling, Vol. 5 , PT1, pp. 73-80.
16. Buddhdev, B. G. and Varia, H. R. : Feasibility Study on Application of Blast Furnace Slag in Pavement Concrete, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 3, Issue 3, pp. 10795-10802, 2014.
17. IS: 2720 (Part 3/See 2) 1980.Indian Standard Methods of Test for Soils Part 3 Determination of Specific Gravity Section 2 Fine, Medium and Coarse Grained Soils.
18. IS: 2720 (Part 2) 1973. Indian Standard Methods of Test for Soils Part 2 Determination of Water Content.
19. IS: 2720 (Part 5) 1985. Indian Standard Methods of Test for Soils Part 5 Determination of Liquid and Plastic Limit.
20. IS: 2720 (Part 7) 1980 Determination of water content -dry density relation using light compaction
21. IS: 2720 (Part16) 1987 Laboratory CBR value
22. IS: 2720 (Part 39) 1977 Direct shear test for soil