Blast furnace dust: An alternative for the improvement of granular material for pavements

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Abstract. The boom in the construction of infrastructure works has encouraged the demand for materials such as steel and natural aggregates, which in turn has generated an increase in the exploitation of materials and the generation of residual iron and steel. This situation has caused double the environmental impact due to the accumulation of these residual materials and the indiscriminate exploitation of non-renewable natural resources. This study was carried out with the aim of analyzing the possibility of using blast furnace dust to improve the properties of granular materials used in the construction of roads, as an alternative to mitigate the environmental problems caused by poor disposal and accumulation of this waste, affecting the areas of influence of these companies. To achieve this objective the physical and chemical properties of fine blast furnace dust was determined and mixtures of materials with a granular base with 0, 2, 4, 6, 8, and 10 percent blast furnace dust were analyzed to find the properties of resistance (California Bearing Ratio and resilient module), plasticity and expansion in the presence of water. The results of this study indicate that blast furnace dust can be used to improve some properties of natural aggregates for use in road construction.

1. Introduction

During the steel fabrication process, different residues are produced amongst which are found slags [1,2] and blast furnace dust (BFD) [3]. The BFD is produced in integrated iron and steel residues during the process of transformation of the iron mineral into cast iron, during which this material, coke and lime are melted at a temperature of 1500 °C. During this process gasses and fine particulate material are generated which is recuperated in the collectors [4]. In Colombia, the only integrated iron or steel producer is Acerías Paz del Río S.A., located in the department of Boyacá, where the production of BFD is approximately 7200 tons per year [5]. Due to the under-utilization of this residue and a general lack of willingness, an environmental problem is created. Taking this into account, the necessity arises to search for an alternative use for this material.

With the use of this residue, the accumulation in producing companies could be reduced and the properties of granular base and granular subbase materials improved; thus, guarantee the use of adequate and resistant materials in the construction of structural layers for pavements. The objective of this research is to evaluate the feasibility of using BFD as a material for the improvement of granular materials used in road construction, complying with technical and environmental requirements.

Very little research has been done internationally in the use of this material for road construction. In Colombia recently and due to the problem generated, the company “Acerías Paz del Río S.A.” is promoting research and favorable results have already been found in the manufacture of asphalt mixtures [6].
2. Materials and methodology
BFD was obtained from the iron and steel producer Acerías Paz del Río S.A. In Figure 1, the visual characteristics. The granular base material was provided by the San Rafael quarry in the municipality of Combita in Boyacá, Colombia.

Figure 1. Blast furnace dust.

The methodology used in this investigation includes three stages: first to understand the chemical characteristics of BFD, for which X-ray fluorescence (XRF) and X-ray diffraction (XRD) tests were carried out along with the taking of micrographs in the scanning electron microscope (SEM). Secondly, to undertake a physical and mechanical characterization of the materials according to the INVIAS regulations [7] and lastly to mix the granular base material with 2%, 4%, 6%, 8% and 10% of BFD and carry out tests to obtain the required parameters in specifications such as resistance, expansion and plasticity.

3. Experimental design
The granular base selected for this study will have to comply with the requirement established for a class A granular base with a type BG-30 granulometry in accordance with article 330-13 of the general specification for the construction of roads published by the “Instituto Nacional de Vías (INVIAS)” [8]. The characterization tests were carried out for the granular base material, the results of which will be the point of comparison for the characteristics of the mixtures with BFD.

4. Results
4.1. Chemical characterization of blast furnace dust
The percentage of weight of each of the components present in BFD is presented in Table 1, the main component is Fe₂O₃ at 77.5%. The CaO/SiO₂ relation indicates the level of alkalinity of the material, in the case of BFD presenting an alkalinity level of 0.9 [9]. Figure 2 is the SEM micrograph of BFD at a scale of 250X, which shows a rough and porous surface texture with rounded subangular edges, which have the characteristic of a strong bond with the particles of natural aggregates and greater water absorption.

| Component | MgO | Al₂O₃ | SiO₂ | P₂O₅ | CaO | MnO | Fe₂O₃ | Otros |
|-----------|-----|-------|------|------|-----|-----|-------|------|
| BFD       | 1.00| 3.60  | 5.50 | 0.20 | 4.95| 3.32| 77.50 | 0.90 |
The application of the XRD technique allows for the quantification of the phases that make up BFD [10,11]. The sample of BFD showed the following principal phases: forsterite (Mg$_2$SiO$_4$), prehnite (Ca$_2$Al(Si$_3$Al)O$_{10}$(OH)$_2$) and iron titanium oxide (pseudobrookite) (Fe$_2$TiO$_5$); peaks were also observed that correspond to magnetite (Fe$_3$O$_4$), hematite (Fe$_2$O$_3$) and wüstite (FeO). In Figure 3 the diffractogram of BFD is shown.

In the investigations of D. Zhang [12] and T. Hu [4] the phases of wüstite (FeO), Hematite (Fe$_2$O$_3$) and Magnetite (Fe$_3$O$_4$) were identified in BFD as in the sample analyzed in this study.

4.2. Optimum percentage of blast furnace dust
With the test results California bearing ratio (CBR) of each percentage of BFD, a diagram was produced of CBR vs. Percentage of BFD with which the optimum percentage of BFD is determined in order to obtain the best results in the improvement of the granular base material, Figure 4. The optimum percentage was found to be 6% with which better material resistance was achieved [13].

4.3. Mechanical and dynamic behavior parameters
To complete a statistical analysis of the mechanical behavior of BFD as a stabilizer in granular bases, tests of CBR resistance, expansion, Atterberg limits were used to determine the plasticity of the material and the determination of the resilient module.

Figure 5 shows the behavior of the resilient module with the increase in BFD content. The behavior is similar to the CBR results. The highest value is obtained with 6% of BFD obtaining an increase of 4% with respect to the value of the resilient module of the material without BFD.
Figure 4. Determination of optimal percentage of BFD.

Figure 5. Resilient module behavior.

Figure 6 shows the behavior of the change in the plasticity index with the increase in BFD. The decrease is noticeable as we increase the content of BFD, until obtaining a non-plastic material with 6% of BFD. The above is of great benefit in the construction of pavement structures.

Figure 6. Plasticity index behavior.
Figure 7 shows the behavior of the percentage of expansion of the granular material with the increase of BFD. With 6% of BFD there is a decrease in the expansion potential of 29%, this decrease is important since if this material is exposed to the presence of water it will not undergo volume changes, which is a very important property in the structural layers of the pavement.

5. Conclusion
The characterization of the granular base material was carried out through the tests required by INVIAS as a quality criterion. This aggregate satisfies a large part of these parameters except for the plasticity index where the material is 5% higher than that established in article 330 and the resistance parameter for a class A granular base, having obtained a CBR of 90%, which is 5% lower than the minimum value required by the regulation. The fine blast furnace dust was characterized, obtaining results that indicate the dust complies with the quality parameters to be used as part of the granular base aggregate.

From the mixtures prepared for the CBR test, it was able to be determined that the optimum dust percentage is 6%, as this was the mixture that obtained the highest value in this parameter, equal to 96%, enough to comply with the minimum value specified by INVIAS for a class A granular base. Moreover, it was determined that at a certain level, the use of fine blast furnace dust starts to become damaging for the mixture as it reduces the resistance of the material, leading to the CBR value with dust dropping lower even than that obtained for the material without the stabilizer. For this reason, it is important to determine the turning point.

As the increase in the CBR of the granular base produced by the stabilization of fine blast furnace dust is not very pronounced, it can be considered as a method of stabilization for materials of which the CBR does not quite comply with that specified by INVIAS although being very close to the acceptance limit.

From the CBR test it was possible to determine that the use of fine blast furnace dust contributes to the reduction of the expansive potential of the samples, thereby improving the volumetric stability as the expansions were seen to be reduced by 1.52% comparing the value obtained from unstabilized material and that of the mixture with 10% fine blast furnace dust.

The consistency limits of the aggregate also benefitted from the use of dust as, once the dust was added, a reduction in the value of the limits and therefore the plasticity index was seen. This led to the sample showing non-plastic behavior, which meant that the granular material used in conjunction with the fine blast furnace dust achieved compliance with the non-plasticity parameter for a class A granular base.
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