Blast furnace dust and phosphorous slag, new materials for use in road engineering

R Ochoa Díaz
1 Universidad Pedagógica y Tecnológica de Colombia, Tunja, Colombia

E-mail: ricardo.ochoa@uptc.edu.co

Abstract. This article proposes an alternative to the use of phosphorus slag and blast furnace dust, by-products of the steel industry, due to the negative environmental impact caused by its accumulation. Taking into account the above, the pertinence of the use of these by-products in asphalt mixtures for the construction of roads is studied. In this way, the origin and its properties are presented, as well as their physical and chemical characteristics. Once the tests have been carried out, it is determined that these by-products have adequate characteristics for their use since they do not present toxicity problems. Following this, the design of the mixtures is carried out to determine the mechanical and dynamic properties and thus determine the proportion to be replaced with the conventional materials. Taking into account the results it is concluded that its use is feasible since the mixture with these by-products presents acceptable resilient modulus parameters and improvement in some verification parameters.

1. Introduction
When you look at the current state of highways in the country, where large resources are invested and pavement structures do not last for the time they were designed, it is necessary to look for new construction methods and new materials that meet the specifications of construction [1]. Taking into account the above, and also, the environmental impact generated by the exploitation of natural materials and the accumulation of steel residues, it could be proposed to use such steel residues within the whole of the road as substitutes for natural aggregates. Thus, it is proposed that the steel residues be incorporated into embankments, granular layers or forming asphalt mixtures, either in the form of coarse aggregate, fine aggregate or mineral fillers [2].

Once the situation is understood, this work is oriented towards the sustainable use of steel residues, especially for phosphorus slag and blast furnace dust in parallel. These residual materials could be incorporated in the design of new asphalt mixtures, a previous step of vital importance for the construction of roads [3]. The residues used in this study are produced by the company Acerías Paz del Río S.A. The dust is produced in the blast furnace and the phosphorus slag is generated in converters [4]. It should be added that these steel residues should comply with the general specifications for road construction materials of INVÍAS [5].

2. Materials and methodology
The dust is generated during the operation of the blast furnace for the production of pig iron, using as raw material iron ore, limestone, and coke. In the combustion process, gas is generated, which is composed of small particles that are trapped and evacuated by the pipe to hoppers. The phosphorus slag
is generated in the converters during the transformation of pig iron into steel. In Figure 1, a photo of the dust is shown. In Figure 2, a photo of the phosphorus slag is shown.

The methodology used in this research is divided into three stages: the chemical and mechanical characterization of the materials, the comparison of the results with the required specifications, and the realization of tests to obtain the working formula using the RAMCODES methodology [6,7].

![Figure 1. Dust of blast furnace.](image1)

![Figure 2. Phosphorous slag.](image2)

The chemical evaluation was performed by means of a Scanning Electron Microscope (SEM) to know the texture of the residues used [8]. Figure 4 shows the SEM image of blast furnace dust at 100μm scale, observing a porous structure that potentially promotes asphalt absorption. Figure 5 shows a SEM image of the phosphorous slag at 10μm scale, which has a rough texture.

The study of the elemental chemical composition was performed by means of an X-ray fluorescence spectrometer in order to establish the components of each of the residues. In order to determine the optimum percentage of asphalt in the mixture, the criteria established in article 450-13 of the road construction specifications of INVÍAS for a transit level of NT3 design were followed: Marshall Stability, flow, and air voids. After verifying the compliance with these parameters, the design was verified by the following tests: adhesion to evaluate the effect of water on the indirect tensile strength of mixtures, resistance to plastic deformation or rutting, indirect stress test to determine the resilient modulus in the NAT (Nottingham Asphalt Tester) equipment, and determine the fatigue laws of asphalt mixtures subjected to dynamic bending.

![Figure 4. SEM micrographs of phosphorous slag.](image4)

3. Experimental design
The mixture chosen for the development of the research is a hot-dense mixture type 19 (MDC-19), article 450-13 INVÍAS [5]. In order to carry out an analysis of the behaviour of the waste, three blends were designed as follows: mixture 1 (M1) with conventional materials (gravel and sand); Mixture 2 (M2) replacing 50% of gravel per slag and replacing 50% of sand with dust; Mixture 3 (M3) completely replacing gravel and sand for slag and dust respectively. Asphalt 60-70 was used for all mixtures.
4. Results

4.1. Characterization of waste

The chemical composition of the wastes is important characteristics that must be considered before inclusion in the asphalt mixtures. Table 1 shows the elemental composition obtained by X-ray fluorescence spectrometry of the dust and slag. The predominant component in the dust is Fe with 77.5% and in the slag, is Ca with 46.8%.

| Component | Mg | Al | Si | P  | S  | K  | Ca | Ti | Mn | Fe  | Zn |
|-----------|----|----|----|----|----|----|----|----|----|-----|----|
| Dust Cont. Unit. (%) | 1  | 3.6| 5.5| 0.2| 1.8| 0.51| 4.95| 0.11| 3.32| 77.5| 1.5 |
| Slag Cont. Unit. (%)  | 2.7| 4.9| 10.8| 2.1| 0.58| 0.52| 46.8| 0.1| 2.0| 28.8| 0.53 |

The physical and mechanical properties of dust and slag are presented in Table 2. These tests were carried out according to the INVIAS road materials test standards [9].

| Feature | Unit | Requirement | Result | Standard |
|---------|------|-------------|--------|----------|
| “Los Ángeles” wear (E) max. | % | 25 | 20 | INV E-218/ASTM C-131 |
| Mechanical resistance (E) min. | kN | 110 | 112 | INV E-224/SABS Metth 842 |
| Flat and elongated particles (E) max. | % | 10 | 1 | INV E-240/ASTM D-4791 |
| Loss of solidity (P) max. | % | 18 | 3 | INV E-220/ASTM C-88-05 |
| Plasticity index (P) max. | % | NP | NP | INV E-126/ASTM D-4318 |
| Sand equivalent (P) min. | % | 50 | 94 | INV E-133/ASTM D-2419 |

E: Phosphorous slag. P: Dust

4.2. Characteristics of the mixtures

The physical and mechanical characteristics of the designed mixtures are presented in Table 3.

| Feature | Unit | M1 | M2 | M3 | Standard |
|---------|------|----|----|----|----------|
| Asphalt content | % | 4.8 | 6.5 | 5.2 | - |
| Marshall Stability | N | 11967 | 10561 | 10896 | INV E-748 |
| Flow | mm | 3.4 | 3.5 | 3.4 | INV E-748 |
| Air vents | % | 4.6 | 6.0 | 5.4 | INV E-736 |

As regards stability, it is observed that mixtures containing phosphorous slag behave very efficiently, and if the coarse aggregate is also related to the stability of the mixture, it is clear that all mixtures meet the minimum value for NT3 which is 9000N. Similarly, the flow meets the required parameters, since it is within the range of 2.0 to 3.5. It is also observed that the requirement of voids with air is fulfilled in the three mixtures. The results of the verification tests of the design of the asphalt mixtures are shown in Table 4.

| Feature | Unit | M1 | M2 | M3 | Standard |
|---------|------|----|----|----|----------|
| Adhesion RRT | % | 87 | 57 | 58 | INV E-725 |
| Rutting | mm | 3.3 | 1.8 | 1.5 | INV E-756 |
| Resilient module at 13°C | MPa | 7200 | 6600 | 8100 | INV E-749 |
| Fatigue-Radial strain | Def. | 0.912 | 0.054 | 0.002 | INV E-784 |
With regard to the rutting test, the specifications require that the deformation rate of the specimen during a range of 105 to 120 minutes should not exceed 15μm/min [10]. The tests performed on the different mixtures show that for this variable the mixtures are satisfactory.

Observing the resilient modulus [11] obtained for the conditions of a rolling layer in a city with a temperature of 13°C, an improvement of the module in the mixture M3 was obtained, and in the case of the mixture M2 the module decreased.

As for the radial deformation, the equations were determined based on a transit of 5 million axes. It was observed that the values meet the criterion required since the asphalt binder is subjected to a number of load repetitions, a situation that must allow a smaller radial deformation, in order to avoid damages to the structure during the service [12].

5. Conclusions

The use of non-conventional materials such as phosphorus slag and blast furnace dust, waste from the steel industry, have a high level of functionality when used as aggregate in asphalt mixtures.

Blends containing blast furnace dust present a higher asphalt content, due to the high absorption capacity and texture of the dust, a situation that directly affects the economic terms.

In general terms, mixtures of dust and slag proportions are technically feasible in design. Although these mixtures are susceptible to moisture and saturation conditions, this drawback can be solved with the application of specialized additives for the improvement of the adhesion of the asphalt mixtures.

The phosphorus slag and the dust meet the requirements and specifications required for the materials to be used in asphalt mixtures, which is why its use is feasible for the manufacture of asphalt mixtures in road construction. In addition to the above, the use of these industrial wastes contributes to the preservation of the environment by preventing their accumulation, and also, reduces the exploitation of natural materials that could be replaced at least in part by such industrial by-products.

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