Use of steel slag as a new material for roads

R Ochoa Díaz, M Romero Farfán, J Cardenas and J Forero

1 Universidad Pedagógica y Tecnológica de Colombia, Tunja, Colombia

E-mail: ricardo.ochoa@uptc.edu.co, miquel.romero@uptc.edu.co

Abstract. This research paper aims to analyse the behaviour of MDC-19 hot dense asphalt mixtures with steel slag as coarse aggregate, by using asphalt 80-100, in order to verify if this residue has suitable characteristics that allow its use. The physical and mechanical characterization was accomplished using phosphorous slag from the company Acerías Paz del Río S.A. The working formula was then determined for each mixture using the RAMCODES methodology, the briquettes were produced in the laboratory and then, the design verification was performed. Taking into account the results obtained, it is concluded that the use of phosphorous slag as coarse aggregate in asphalt mixtures is workable, since acceptable design parameters and verification are obtained that meet the specifications for use as a rolling layer.

1. Introduction

Engineering is constantly faced with problems such as the demand for materials that meet the previously established technical requirements and ensuring their continuous supply. The design of asphalt mixtures with waste can be the solution to reuse waste from the steel industry and mitigate the environmental effects produced by the indiscriminate exploitation of natural resources [1]. Furthermore, this would enable offering pavement structures that meet all INVIAS specifications [2]. In addition, residues that offer geotechnical and hydraulic properties equivalent or superior to that of conventional granular materials can be found [3].

The phosphorous slag used in this study is a residue from the company Acerías Paz del Río S.A., which is generated in converters for the transformation of pig iron into steel [4]. With the results obtained it will be possible to implement the steel waste in the elaboration of pavement structures for different levels of traffic, which would be of great benefit economically and environmentally, in order to reduce the exploitation of natural resources, for use of aggregate in Roads, and environmental pollution caused by waste in the steel industry [5].

2. Materials and methodology

The steel residue used in this study is phosphorous slag, as shown in Figure 1, which is produced in integrated steelworks, in the converters [6]. This process is carried out for the transformation of pig iron from the blast furnace into steel. Figure 2 shows a SEM image at 10µm scale, in which the rough surface texture of the slag can be observed [7].

The stone materials used in this work are from “La Roca” Shredder, located in the municipality of Moniquirá (Boyacá) and the sand is supplied by the “Solarte and Solarte” consortium in the city of Tunja (Boyacá). Asphalt type 80-100 was the binder used.

The methodology used in this research is based on three stages: physical, chemical and mechanical characterization of the aggregates to be used; preparation of the laboratory mixtures for the working formula using the RAMCODES methodology [8,9] and, verification of the design to make the
comparision of the most representative parameters of the mixtures and thus, to be able to define and establish the use of this residue. All the tests were carried out in the pavement laboratory of the “Universidad Pedagógica y Tecnológica de Colombia”.

3. Experimental design and results
Three blends were made for the development of the research: mixture A, with conventional stoneware (sand and gravel); mixture B, substituting 50% of the coarse aggregate for slag and C mixture, replacing 100% of the coarse aggregate with phosphorous slag. All mixtures were adjusted to the granulometry of a MDC-19 blend.

3.1. Characterization of aggregates and slag
The characterization of the stone aggregates and phosphorous slag must show an excellent behaviour when subjected to conditions of work in the field. The aggregates are submitted to laboratory processes in accordance with the requirements of the INVIAS general road rules and specifications [10] and thus to evaluate the characteristics of the asphaltic mixtures. The results of the characterization of the stone aggregates are shown in Table 1.

| Table 1. Properties of stone aggregates (gravel and sand). |
|---------------------------------|---|---|---|---|
| Feature                        | Unit | Requirement | Result | Standard |
| “Los Ángeles” wear max.        | %   | 25          | 20     | INV E-218 |
| Loss of solidity max.           | %   | 18          | 3.2    | INV E-220 |
| Fractured faces min.           | %   | 85          | 94     | INV E-227 |
| Impurities max.                | %   | 0.5         | 0.45   | INV E-237 |
| Sand equivalent min.           | %   | 50          | 68.5   | INV E-133 |
| Plasticity index max.          | %   | NP          | NP     | INV E-126 |

As shown in Table 2, phosphorus slag used as coarse aggregate meets the requirements stipulated by the standards for coarse aggregates to be used in asphalt mixtures.

| Table 2. Properties of phosphorous slag. |
|---------------------------------|---|---|---|---|
| Feature                        | Unit | Requirement | Result | Standard |
| “Los ángeles” wear max.        | %   | 25          | 20     | INV E-218 |
| Loss of solidity max.           | %   | 18          | 1.7    | INV E-220 |
| Fractured faces min.           | %   | 85          | 91     | INV E-227 |
| Impurities max.                | %   | 0.5         | 0.2    | INV E-237 |
3.2. Features and comparison of mixtures

Observing Figure 3, it can be established that the three designed mixtures exceed the minimum stability of 9000N, required by INVIAS specifications [1]. The stability results indicate that the coarse material (gravel and phosphorous slag) have good friction and bonding between particles, which makes the mixtures not vulnerable to high rutting problems during their useful life, maintaining their shape when under compression from loads produced by traffic.

![Figure 3. Stability of the mixtures.](image)

As for the resilient modules, it was calculated for three specimens made from the working formula for each type of mixture. The Bulk gravity and the module by the principle of indirect voltage at a temperature of 25°C were determined [11]. The principle states that by applying a compressive load across the diameter of a cylindrical sample a voltage is produced on an orthogonal diameter to which the load is applied. The resilient modules were made at a frequency of 10Hz and at temperatures of 5.25 and 40°C. Each temperature was tested twice: first in its initial position and second with a specimen turn of 90°, with respect to the starting point.

The plastic deformation (rutting) was determined in the laboratory in a test consisting of subjecting a briquette of each mixture to the passage of a wheel [12], for which the depth of the produced deformation was periodically measured at 60°C.

The results of the plastic deformation test and other verification tests of the design of the mixtures are shown in Table 3. In this it is observed that the mixtures M-A and M-B comply with the adhesion parameter (minimum 80%), while the mixture M-C does not comply. The rutting presented in the three blends is very similar, fulfilling the established requirements.

| Table 3. Features and properties of the mixtures. |
| Feature | Unit | M-A | M-B | M-C | Standard |
| Adhesion RRT | % | 87 | 80 | 50 | INV E-725 |
| Rutting | mm | 1.85 | 2.20 | 2.30 | INV E-756 |
| Resilient module at 13°C | MPa | 5100 | 3970 | 1830 | INV E-749 |
| Fatigue-radial strain | Def. | 0.26 | 0.24 | 0.22 | INV E-784 |

4. Conclusions

The design of type MDC-19 hot dense asphalt mixtures, with phosphoric slag as coarse aggregate was carried out using the RAMCODES methodology. With the fulfillment of the void percentages. The optimum asphalt content of 4.7% was obtained for the M-A mixture, 6.4% for the M-B mixture and a percentage of 9.3% for the M-C mixture (for steel residues). The increase in the percentage of asphalt in the modified mixtures is due to the fact that the slag is a material with great porosity, resulting in increased costs for the design of mixtures with these materials.
The phosphorous slag used as coarse aggregate meets the requirements stipulated by the standards, especially the wear on “Los ángeles” machine, a fundamental parameter in the behaviour of the asphalt mixture.

When determining the resilient module for the temperature of Tunja (13°C) for each of the mixtures, it was possible to establish that the value of the modified mixture M-C (1810MPa) is low in relation to the mixtures M-B (3970MPa) and mixture M-A (5100MPa). If actual operating conditions are used in which repeated loads of traffic and temperature increase are generated, there will be a shortening of the life of the tread layer, due to the appearance of exudation problems and generation of repetitive deformations.

References
[1] Francisco S 2002 Utilización de residuos en la construcción de capas de firmes de carreteras Ingeniería Civil 128 72
[2] Instituto Nacional de Vías 2013 Especificaciones generales de construcción de carreteras (Bogotá: INVIAS)
[3] Rahman A, Imteaz M, Arulrajah A, Piratheepan J and Disfani M 2015 Recycled construction and demolition materials in permeable pavement systems: geotechnical and hydraulic characteristics Journal of Cleaner Production 90 184
[4] Gómez A 2002. Proceso siderúrgico planta Belencito (Colombia: Acerías Paz del Río S.A.)
[5] Gulnur M, Filiz B, Tanju K and Ulku Y 2016 The environmental impacts of iron and steel industry: a life cycle assessment study Journal of Cleaner Production 130 195
[6] Wu W, Meng H, and Liu L 2013 Melting characteristics of recycling slag in descarburization converter and its application effects Journal of Iron and Research, International 20 7
[7] Chao L, Zongwu Ch, Shaopeng W, Bo L, Jun X and Yue X 2017 Effects of steel slag fillers on the rheological properties of asphalt mastic Construction and Building Materials 145 384
[8] Sánchez F, Garnica P, Larreal M and López D 2011 Polyvoids: Analytical tool for superpave HMA design Journal of Materials in Civil Engineering 23 1129-1137
[9] Sánchez F, Garnica P, Gómez J and Pérez N 2002 Ramcodes: Metodología racional para el análisis de densificación y Resistencia de geomateriales compactados Instituto Mexicano del Transporte 200 29
[10] Instituto Nacional de Vías 2013 Normas de ensayos de materiales para carreteras (Bogotá: INVIAS)
[11] Muhammad K, Hamid N, Surya S and Laksmi I 2017 Laboratory experiment on resilient modulus of BRA modified asphalt mixtures International journal of Pavement Research and Technology 10 5
[12] Preeda Ch and Hussain U 2017 Mechanisms of asphalt mixture rutting in the dry Hamburg Wheel Tracking test and the potential to be alternative test in measuring rutting resistance Construction and building Materials 146 176