Preparation of concrete mixtures with electric arc furnace slag and recycled ground glass

Y Pérez Rojas¹, E Vera López¹, M López Rodríguez¹ and J Díaz Pita¹
¹ Universidad Pedagógica y Tecnológica de Colombia, Tunja, Colombia

E-mail: yasmin.perez@uptc.edu.co

Abstract. The present work includes the first advances in the development of investigations that seek to include Ground Grinding Glass (GRR) and the Electric Arc Furnace Slag (EAFS) in the production of mixtures of hydraulic concrete mixing them simultaneously, so that it satisfies the specifications techniques to be used in the construction of rigid pavements. Firstly, we cite the tests carried out on the different materials to obtain their physical, chemical and mechanical characterization and determine their compliance, as well as the measurement of certain characteristics that may be somewhat empirical to standardize their control. Techniques such as X-Ray Diffraction (XRD), X-ray Fluorescence Spectrometry (XFR) and Scanning Electron Microscopy (SEM) have been used. Once the results of the characterization tests and their correspondence with the Colombian technical standards have been obtained, it has become possible to select the use of the Transparent Recycled Ground Glass (TRGG) as the most suitable for the replacement of the sand in the dosage of new mixtures modified concrete.

1. Introduction
The present paper contains the advances in the development of the doctoral thesis denominated "Replacement performance in concrete aggregates, by EAFS and RGG, and corrosion analysis." in which it is tried to demonstrate the feasibility of the use of industrial residues in the construction of rigid pavements. The waste to be used is the Electric Arc Furnace Slag (EAFS) as a substitute for the coarse aggregate and the Recycled Ground Glass (RGG) as a substitute for the fine aggregate. The research is in an early development, approximately 25% so the data and observations recorded in this document are limited to the characterization of the new materials to be incorporated into the mixtures of the hydraulic concrete, especially to the characteristics related with RGG, which have not been easily obtained within the current literature, especially geographically demarcated for the department of Boyacá (Colombia). In addition, it presents an updated bibliographic revision of the use of EAFS and RGG as substitutes in the mixtures of hydraulic concrete, without being used simultaneously, as is the fundamental of this research, being a novel advance of great impact when implementing its use in the construction of the road infrastructure.

The research is experimental and seeks to evaluate the behaviour of reinforced hydraulic concrete, useful in the construction of infrastructure works, modified in its dosage gravel by EAFS and RGG in replacement of the sand. The properties to be evaluated are the simple compression strength, corrosion resistance of reinforcing steel, density, voids and absorption. Electronic Scanning (SEM/EDX) and X-Ray Diffraction (XRD) will be employed.
2. Industrial waste in Colombia

Industrial waste from steel has ceased to be by-products to be part of cement and construction raw materials [1]; however, there is a need to expand knowledge, techniques, methods and regulations that guarantee the efficiency of its use. Slag production in Colombia is between 0.1 and 0.3 tons per ton of steel produced. According to Diaco SA internal records, the amount of black slag generated for 2009 was 53.122 tons from 327.250 tons of scrap for a production of 280.354 tons of steel, i.e. 16.2% of the scrap is converted into Slag during the process [2]. In its use as an aggregate for concrete, the crystallized slag offers properties of excellent adherence with cement, stability of volume and durability, and fire resistance superior to that obtained with other aggregates.

Glass in turn and due to the population increase in Colombia and its settlement in urban centres has become one of the main post-consumer waste, especially its presentation in bottles that saturate at a great pace the dumps and landfills, and its improper disposal reach water sources [3].

Table 1 shows the volumes of glass (bottles) that are generated in the sanitary landfills of the main cities of Colombia.

Table 1. Glass volumes generated in landfills.

| Department      | Waste Description | Tonne/day | Landfills     |
|-----------------|-------------------|-----------|---------------|
| Bogotá          | Solids            | 6300      | Doña Juana    |
|                 | Bottles (4.6%)    | 290       |               |
| Antioquia       | Solids            | 3260      | Pradera y Guacal |
|                 | Bottles (3%)      | 98        |               |
| Valle del Cauca | Solids            | 3072      | Yotoco        |
|                 | Bottles (2.56%)   | 79        |               |
| Atlántico       | Solids            | 1907      | Los Pocitos   |
|                 | Bottles (1.58%)   | 30        |               |

3. Materials and testing

The research is carried out with natural silica sand with modulus of 2.41 fineness and specific gravity of 2.42 and limestone of 19mm of maximum nominal size as aggregates for concrete. The recycled ground glass is used with particles smaller than 4.75mm and specific gravity of 2.49. The EAFS has a maximum nominal size of 19mm and a specific weight of 3.28. The cement to be used is ordinary Portland cement in accordance with ASTM C150 and INV-307-13 with a specific gravity of 2.855 according to the test performed. The recycled glass was classified by colour by selecting two types, Green Recrystallized Ground Glass (GRGG) and Transparent Recycled Ground Glass (TRGG).

3.1. Aggregates

The main physical and mechanical characteristics of the aggregates are presented in Table 2.

Table 2. Physical and mechanical characteristics of gravel and sand.

| Material | Materials finer 75μm | Specific gravity | Absorption UWLa | UWrb | Angeles machine | Micro-Deval |
|----------|-----------------------|------------------|------------------|------|----------------|-------------|
| Gravel   | 0.05                  | 2.420             | 1.746            | 1.326| 1.442          | 36.08       | 23.74       |
| Sand     | -                     | 2.600             | 1.208            | -    | -              | -           | -           |
| EAFS     | 0.01                  | 3.277             | 1.877            | -    | -              | 19.67       | 6.96        |
| RGG      | -                     | 2.494             | 0.806            | -    | -              | -           | -           |

3.2. Electric arc furnace slag

The oxidizing slag of the electric arc furnace is a by-product of the steel industry, generated after the melting and the refined acid preliminary liquid steel. It is a stone material that is easy to crush for use as an aggregate in concrete mixtures [4].
Slags have been used as an addition or in proportional combination with Portland cement for the manufacture of concrete or mortars. The use of slag in construction has recently increased [5]. In the United States and Europe, slags have shown good performance over time, indicating that they can be effective in reducing pore size, thus taking less waterproofing and longer durability of concrete mixtures. Concrete combined with slag has many advantages: increased durability, moderate heat of hydration, higher compressive strength, and lower permeability, superior resistance to alkali silica reaction due to penetration of chloride ions and sulphate ions, workability, environmental and economic value [6].

Slags are composed of lighter compounds than steel, which rise to the surface of the metal bath, forming a layer of variable thickness. These compounds are mostly oxides, silicates, sulphides, aluminates and phosphates, which form as a consequence of the technological process of obtaining steel [7].

In order to perform the EAFS characterization in the INCITEMA laboratory of the “Universidad Pedagógica y Tecnológica de Colombia”, the X XFR test was carried out for the analysis of the chemical composition of the EAFS, observed in Table 3.

**Table 3. Chemical composition of the EAFS (%)**

| Compound | Mg | Al | Si | S   | K   | Ca | Ti | Cr | Mn | Fe  | Zn |
|----------|----|----|----|-----|-----|----|----|----|----|-----|----|
| Concentration | 4.0 | 7.0 | 14 | 0.33 | 0.20 | 26.7 | 0.58 | 1.2 | 6.68 | 38.8 | 0.46 |

3.3. *Recycled ground glass*

Glass is an amorphous material produced by melting silica, sodium carbonate and calcium carbonate (CaCO₃), followed by cooling, during which solidification can occur without crystallization [8].

This material comes from the collection at the source of waste such as glass bottles and transparent green containers, which are washed in a soapy solution, to remove labels and residues and then disinfected with 0.1% chlorine bleach solution concentration. They are then dried to constant mass and broken, to be brought to the Los Angeles machine for 10 minutes at 500rpm. Once ground, it is passed through #4 sieve. The retained material is re-ground for the same period of time. The material to be incorporated into the new concrete mixtures is the one that passes through the #4 sieve.

The recycled glass used as an aggregate in the concrete causes surface cracks in the concrete due to the expansion generated by the ASR (alkali - silica) reaction between the amorphous silica present in the glass and the cement paste of alkaline nature [9]. For this reason, the expansion in both types of glasses was studied, so that it was possible to establish the parameter to be controlled and the convenience in the selection of the type of glass to be used. Is of major importance the study of the alkali-silica reaction due to the large amount of amorphous silica in the glass [10].

**Figure 1. XRD in GRGG.**
Within the glass characterization process, the XRD was used to define the chemical composition and the morphology and microstructure was studied by SEM. Green and clear recycled ground glass samples were obtained from material passing the #100 mesh (150μm). XRD tests on both green glass and clear glass showed that it was an amorphous material as seen in Figure 1. The green glass showed a diffraction peak which, when analysed by the test of Rutile, corresponds to quartz and coesite in a percentage of 1.9% and 3.8% respectively.

The green and transparent glass was analysed by scanning electron microscopy (SEM) to determine its morphology and microstructure. In Figures 2 and 3, the values or particle size and twins present in the milling process is observed.

![Figure 2. Particle size and twins in GRGG.](image)

![Figure 3. Particle size and twins in TRGG.](image)

4. Discussion

According to current Colombian regulations for the production of concrete aggregates, the aggregates proposed in the research comply with the specifications. The coarse aggregate by its particle size distribution corresponds to an aggregate AG-2. For the gradation of the master mix the adjustment of the theoretical curves will be done according to Fuller [11].

The granulometry of the aggregates associated with the compactness of the concrete, as well as its quality, influences the workability of the fresh mixture, the mechanical resistance, the resistance to the chemical agents and in the economy in the production of hydraulic concretes [12]. For this reason, actors like Fuller and Bolomey developed ideal grain sizes to achieve maximum compactness and thus guarantee the quality of the concrete.

The design mix will be a blend of plastic consistency, 50 mm settling, 50% flowability, and ideal blend for reinforced retaining walls, foundations, normally compacted paving, slabs, beams and poorly, reinforced columns.

The method of design of the mixtures will follow the methodology ACI 211, the variation of the percentage of slag in 25%, 50%, 75% and 100% will be carried out in replacement of the coarse aggregate content in the standard sample and of 20% 30% and 40% of the content of fine aggregate.

In view of the results of the expansion test on samples of recycled ground glass, it is concluded that when the same expansion is present and because the generation of volumes of transparent glass is greater, experimentation will be carried out with the ground glass recycled transparent for the elaboration of the modified concrete mixtures as a replacement of the fine aggregate.

5. Conclusions

This study is in an initial stage of development and seeks to incorporate industrial waste in the manufacture of concrete mixes for pavements.

In the expansion test it was verified that there is no significant difference in the expansion presented by transparent glass and green glass.
The replacement materials comply with the Colombian technical specifications in terms of granulometry.

The artificial aggregates (glass and EAFS) have the same fineness modulus of sand and gravel respectively.

To find the percentages of the aggregates fitted the ideal curve of Fuller, the fineness modulus method was used. The method considers the modulus of fineness of the aggregates to be used and the fineness modules of the Fuller curve and a system of 2 equations was proposed with 2 unknowns that allow the determination of the proportions of the aggregate in the mixture.

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