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Life Cycle Assessment of Concrete Products for Special Applications Containing EAF Slag

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Abstract

Electric Arc Furnace (EAF) slags are steel slags that derive from the steel manufacturing process and are produced in large volumes (~10% of the steel produced) worldwide, which pose an environmental threat when disposed in landfills. Their physicochemical characteristics (high density, roughness and resistance to fragmentation) favor their use in concrete products for special applications, especially where high resistance to abrasion is required and the increase concrete density is not a problem. The special concrete applications considered in this paper were industrial pavements, heavyweight concrete and pervious concrete paving blocks and all proposed products were designed in order to perform in a similar way as reference products with ordinary concrete. Then, in order to quantify the benefits arising from the utilization of an –otherwise useless– industrial by-product, a Life Cycle Assessment was carried out for each of the concrete products. One m^3 or one m^2 of concrete was selected as functional unit and a cradle-to-gate approach was followed for the LCA, including material extraction, transport and production and placement, stating the limitations and system boundaries used. Cost estimation for each of the products was also performed in order to assess their commercial viability. The results show that for industrial pavement construction, concrete with EAF slag aggregates has similar environmental load and cost with the reference concrete, while in the case of pervious paving blocks the use of EAF slag aggregates reduces the environmental load by 14% at a reduced cost, and for heavyweight concrete the environmental load is reduced by 44% at a significantly lower cost.

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Keywords: LCA; concrete products; EAF slag.

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1. Introduction

Slags are the industrial by-products of the steel production process. Depending on the production method, slag accounts for 7.5-15% of the total steel produced, and the total annual world production is estimated at 470-610 million tons for 2015[1]. Annual steel slag production in Greece is about 250,000 tons and consists only of Electric Arc Furnace (EAF) steel slag. The melting of scrap for the production of steel in an electric arc furnace is common practice in many countries[2] and two types of slag are produced with this process; The first is Electric Arc Furnace Slag (EAFS), which is produced in granulated form during the first stage of steel production and the second is Ladle Furnace Slag (LFS), which is a fine material produced at the second stage of steel production after the addition of fluxes to the molten slag in a ladle. EAFS is a granular by-product that could find uses as aggregate in concrete applications[3], while LFS shows a different chemical composition compared to EAFS, with significantly lower content in ferrous oxides and increased fineness[4]. The chemical compositions of both steel slag and LFS vary depending on the batch synthesis, due to the fact that in scrap melting the production is carried out in batches, as opposed to the continuous process of blast furnace steel making. Furthermore, local conditions, different manufacturing practices, and scrap metal variations could also affect significantly the chemical composition of the produced slag[5].

The primary uses of EAFS in civil engineering applications include cement clinker production or as aggregate in roadbeds and asphalt concrete. These uses have been common practice for a long time, even from the beginning of the 20th century[6]. However, only recently there has been an attempt to establish a relative regulative framework in Europe[7], while standards for EAFS use in concrete applications, such as concrete pavements exist in Japan[8]. The use of steel slag in concrete is part of the main research activities of the AUTH Laboratory of Building Materials, in an effort to contribute towards the utilization of industrial by-products and also to establish the general social and economic framework through which industrial by-products could be incorporated by the construction sector.

The scope for using alternative materials in concrete production is twofold; it can provide some technical improvements to the final product, but it is also expected to be beneficial from an environmental point of view. Amongst the technical advantages of using EAFS aggregates in concrete are high resistance to abrasion, increased apparent specific density and surface roughness of the EAFS granules, that enhances the bond of cement matrix to the aggregate[9,10]. Relevant research regarding heavy metals leaching potential from EAFS has shown that when their chemical composition is within certain limits, leaching does not take place[11]. Quality control testing of the EAFS aggregates before use is essential also, in order to avoid expansion[12]. On the other hand, the use of steel slag in concrete production is expected to provide some environmental benefit, mainly due to the utilization of an otherwise useless material. The environmental benefit needs to be determined and measured; otherwise the whole environmental aspect remains unclear. The Life Cycle Assessment (LCA) methodology is commonly used to evaluate and compare the environmental impact of the different cases, based upon International Standards[13,14]. Several research efforts have attempted to model the environmental impact of different construction products through LCA, such as Portland cement[15], bricks[16], pavements[17] and ready-mixed concrete[18], while others have attempted to measure the benefit of using alternative construction materials, such as recycled aggregates[19,20], waste glass[21] and alternative binders[22]. Existing research showcases that although life cycle inventories compiled for each individual research can serve as a global reference database, actual LCA results are largely dependent on local conditions and can vary significantly. For example, the amount of energy required per km of aggregate transportation with a 28 t diesel truck can be similar universally, but the transportation distance required may vary greatly, ultimately changing the environmental footprint of aggregate production and use.

In this paper, EAF steel slag was used as aggregates for the development of concrete for industrial pavements, heavyweight concrete and pervious concrete paving blocks. The mechanical and elastic properties, as well as the durability of slag based concretes were tested in laboratory scale and compared with reference mixtures. Then, an environmental assessment of the research outputs was carried out, with the Life Cycle Assessment methodology, assuming that the outputs would be implemented in actual infrastructure. In addition, a cost estimation of such an implementation was conducted, regarding only the construction phase, because a further economic analysis for such a hypothetical case was considered to produce results of disputed accuracy.