FEASIBILITY STUDY AND CRITERIA FOR EAF SLAG UTILISATION IN CONCRETE PRODUCTS

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Introduction

Electric Arc Furnace Slags (EAFS) are by-products of the steel industry of mainly South-European countries, such as Greece, where it is the only type of slag produced. According to the literature[1,2,3,4,5], long term research and pilot applications, the benefits from the use of EAFS as aggregates and Ladle Furnace Slag (LFS) as supplementary cementitious material in construction applications are many and they can be identified by three interconnected aspects; environmental, financial and quality. Regarding the environmental aspect, the use of slags as aggregate is effective in terms of natural resources preservation, as well as landfill reduction[6]. The reduced cement consumption is also beneficial for the reduction of greenhouse gas emissions[7]. From the financial point of view, there is actual profit from the replacement of conventional costly materials with industrial by-products. The utilisation of slags also supports the so-called 'circular economy; the waste or by-product from one industry becomes raw material for another. The third and most important aspect is that of the quality of the proposed concrete products. Indeed, in many concrete infrastructure projects, considerable technical advantages resulted from the use of steel slags[4,5].

However, the existing regulative frames for concrete do not cover the use of EAFS and LFS as aggregates and supplementary cementitious materials, respectively, to a satisfactory extent. This means that safety issues are not covered and the promotion of steel slag in the construction market is difficult. In the past, many failures have been reported in concrete with steel slags, such as delayed expansion due to free CaO or MgO content, susceptibility to frost or ecotoxicity leachates[3,8]. Therefore it seems that updates are required in the relevant standards, as well as performance type criteria for the use of steel slag in concrete.

Feasibility Study

In order to assess steel slags utilisation in concrete applications and measure its benefits, in the most distinct possible way, five different concrete products/applications were investigated: an industrial pavement (IP), pervious paving blocks (PB), heavyweight concrete for shielding applications (HC), shotcrete (SC) and

ready mixed repair mortar (RM). For each of the applications part of aggregates and/or binder was replaced by steel slags, aiming at equal or improved properties compared with reference concrete products. Since equal performance is not always feasible due to the nature of steel slag by-products (higher density, increased water absorption, increased hardness compared to natural aggregates), the effects of steel slag use on the properties of each concrete product are summarised in Table 1.

Table 1: Alterations in concrete mixtures for each application

Application	Alteration in mixture	Properties improved	Properties unaltered	Properties decreased
Industrial pavement	Replacement of coarse limestone aggregates with EAFS aggregates	Compressive strength, Elastic modulus, Flexural strength, Fracture toughness, Abrasion resistance, Impact strength, Freeze-thaw resistance	-	-
Pervious blocks	Total replacement of all limestone aggregates with EAFS aggregates	Abrasion resistance, Permeability	Compressive strength, Elastic modulus	Flexural strength, Freeze-thaw resistance
Heavyweight concrete	Total replacement of all limestone aggregates with EAFS aggregates	Compressive strength after exposure to high temperature, Elastic modulus, Flexural strength	Compressive strength	-
Shotcrete	Replacement of 33% of binder with LFS	-	Compressive strength, Elastic modulus	-
Repair mortar	Replacement of 20% of binder with LFS	-	Compressive strength, Flexural strength, Shrinkage	Adhesion, Capillary absorption

The environmental behaviour of the reference and the proposed concrete products was assessed using the Life Cycle Assessment methodology[9,10]. Data for the assessment were collected mainly from Greek industries and from European

databases where local data were not available. For the financial performance, a cost assessment was conducted, with data from the Greek market, regarding the period 2014-2015. Table 2 shows the results for both the financial and environmental performance of the concrete products investigated, in the reference mixtures and in the mixtures modified with steel slag products, as described in Table 1. Note that the functional unit for the industrial pavement and the pervious blocks was 1 m^2, while for heavyweight concrete, shotcrete and repair mortar was 1 m^3. Cost was expressed in € per functional unit, while environmental performance in kg CO_2 equivalent per functional unit.

Table 2: Cost and environmental performance for each application

Application	Cost		Environmental performance	
	Reference	Steel slag	Reference	Steel slag
Industrial pavement	22.0 €/m^2	22.9 €/m^2	100 kg $CO_{2,eq}/m^2$	108 kg $CO_{2,eq}/m^2$
Pervious blocks	2.55 €/m^2	2.30 €/m^2	19.5 kg $CO_{2,eq}/m^2$	16.8 kg $CO_{2,eq}/m^2$
Heavyweight concrete	452.7 €/m^3	188.8 €/m^3	903 kg $CO_{2,eq}/m^3$	503 kg $CO_{2,eq}/m^3$
Shotcrete	41.7 €/m^3	41.4 €/m^3	449 kg $CO_{2,eq}/m^3$	306 kg $CO_{2,eq}/m^3$
Repair mortar	56.4 €/m^3	84.7 €/m^3	455 kg $CO_{2,eq}/m^3$	384 kg $CO_{2,eq}/m^3$

The quality assessment was based on the above-mentioned laboratory tests for different physicomechanical and durability properties of the products. In order to take quality into account, weighting factors were used for each property, depending on the desirable properties for each product. Thus, Figure 1 was created, where the ratio of improvement or decrease when using steel slag was calculated, compared to the reference concretes regarding environmental performance, cost and quality for each product. The results show that steel slag use in concrete needs to be orientated at specific applications showing maximum benefits, such as heavyweight concrete and pervious paving blocks. Since there are considerable gains from steel slag use in concrete, a suitable regulative frame needs to be establish in order to promote their safe utilisation.

The use of EAFS as aggregates in concrete must comply fully with EN 12620[11] and especially with the part Annex ZA about dangerous substances. However, specific limits should be established as in the case f air-cooled blast furnace slags. For example, to enhance the good performance of EAFS, limits in constituents content, affecting the volume stability, should be placed.

Based on research[2], the LFS can be used as addition type I or II according to EN 206[12]. Unfortunately, the lack of European or National Specification for the use of LFS as cementitious material, limits its market.

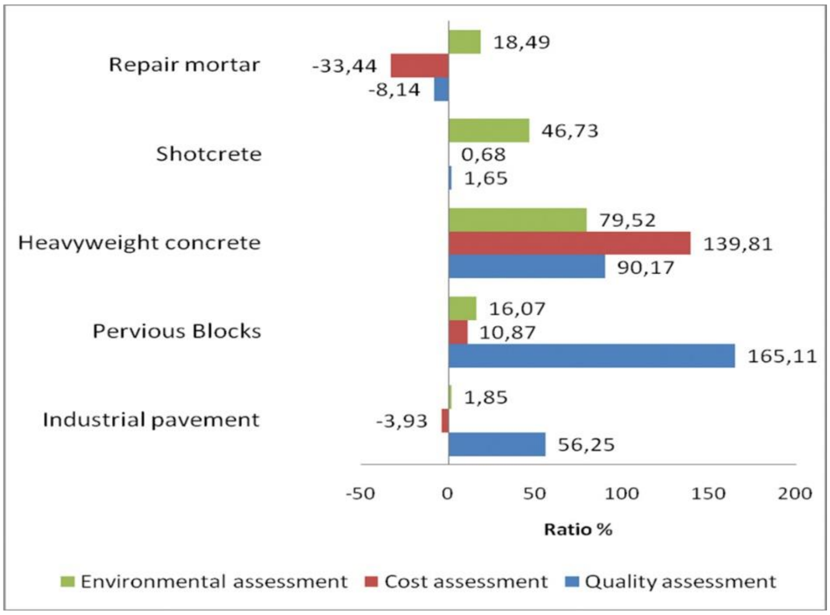

Figure 1: Environmental, Cost and Quality assessment results for each application

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