eman ta zabal zazu

Universidad del País Vasco Euskal Herriko Unibertsitatea

Ingeniaritza Goi Eskola Teknikoa
Escuela Técnica Superior de Ingeniería
Bilbao

DEVELOPMENT OF CEMENTITIOUS MATRIX MATERIALS, WITH IMPROVED PERFORMANCE, INCORPORATING BY-PRODUCTS FROM THE STEELMAKING INDUSTRY

Author

Amaia Santamaría León

Supervisor

Jose Tomás San José Lombera

Eduardo Rojí Chandro

May 2017, Bilbao

SCM
SOSTENIBILIDAD CONSTRUCCION Y MATERIALES
GRID
GRUPO DE INNOVACION Y DISEÑO

AREA CIENCIA DE MATERIALES
AREA MECANICA DE FLUIDOS
AREA CONSTRUCCION

Agradecimientos

Siempre supe que escribir los agradecimientos no iba a ser tarea fácil. Por ello, lo primero quiero pedir disculpas por si me olvido de alguien. Me siento realmente afortunada, por todas las personas que me han ayudado a lo largo de estos 3 años y medio, en los que se ha desarrollado la presente tesis doctoral.

Quiero agradecer al grupo de investigación consolidado IT781-13, por los fondos invertidos en la presente investigación, especialmente por el PIFG005/13. Extender el agradecimiento a todos sus miembros, por sus enseñanzas durante estos años, su apoyo y su trato personal, pero especialmente por haber confiado en mi acogiéndome como un miembro más del grupo.

Agradecer a la Universidad del País Vasco (UPV/EHU), en especial al Vicerrectorado de Investigación, por la financiación aportada a través de la convocatoria de contratación de personal investigador en formación 2013. Tengo que agradecer también al departamento de Ingeniería Minero Metalúrgica y Ciencia de los Materiales por haberme acogido. En especial a mis compañeras que me han apoyado y animado en este camino, y que me han ayudado mucho en mis primeras experiencias en la docencia universitaria.

Agradezco al Ministerio de Economía y Competitividad (MINECO) y a los fondos FEDER la financiación de la presente investigación mediante el Proyecto BIA2014-55576-C2-2-R. No me puedo olvidar de agradecer a todos y cada uno de los miembros del proyecto BLUECONS la gran ayuda que me han proporcionado durante el desarrollo de la tesis, realmente creo que sin vosotros esto no hubiera sido igual. Incluyo en este grupo a Bengo, el mejor alumno de grado que se puede tener.

A los miembros de la división de construcción sostenible de Tecnalia, de LADICIM de la Universidad de Cantabria, de ERAIKER y del laboratorio de Construcción de la Univesisdad de Burgos agradezco la ayuda prestada, y los conocimientos que me han transmitido.

I gratefully acknowledge to Professor Carlo Pellegrino for giving the chance of being one of his team member and to all the people that made my stay in Padova such good experience, especially to Flora Faleschini for helping me so much, and Lesley, Christian and Jaime for all the good experiences.

A mis directores, Tomás y Eduardo, les agradezco en primer lugar haber apostado por mí, confiar (más que yo) en que era capaz de realizar este trabajo y el apoyo que me han brindado durante el desarrollo de la tesis. No puedo olvidarme de Javier, gracias por tu paciencia y por enseñarme tanto. Espero poder seguir disfrutando de tu conocimiento durante muchos años, tanto el académico (que es mucho), como el personal, creo que consigues que los que te rodeamos seamos un poco mejores personas.

Para finalizar agradezco a mi familia (tanto la nueva, como la de siempre) estar ahí siempre y apoyarme tanto. A mis Tartarugas agradecer que siempre habéis estado conmigo y en esta etapa no ha sido menos. A la cuadri de Algorta gracias por el apoyo que me habéis dado, por todo lo que me habéis escuchado y sobre todo por todos los buenos ratos juntos. Ama aita sin vosotros, sin vuestra educación, enseñanzas, cariño y apoyo nunca habría llegado aquí, gracias por todo. Y a ti, maitia, qué decir, creo que en esta página solo puedo decir gracias por tanto.

Summary

Summary

One of the most important industries in the north of Spain, especially in the Basque Country, is the steelmaking industry. The production of steel in electric arc furnaces, prevalent in this small region generates huge amounts of industrial steelmaking waste that have to be properly managed. For many years, the Electric Arc Furnace (EAF) slags generated by the steelmaking industry have been dumped as waste material in landfill sites. Nevertheless, many researchers have been investigating ways of standardizing the use of EAF slag in construction and civil engineering, so that it can be used as aggregate in hydraulic and bituminous mixes. In this way, dumping sites will be relieved of this waste and the consumption of natural resources will be decreased.

In this PhD thesis, a step forward has been taken towards standardization of the re-use of waste materials from the steelmaking industry as raw materials in the manufacture of hydraulic mixes for their use in the construction industry. It has been demonstrated that, with the correct mix design, EAF slag concrete of the desired workability may be manufactured and that it can even perform well in real-scale structural elements.

Real-scale Reinforced Concrete (RC) beams with both pumpable and self-compacting concretes have been manufactured to achieve this goal. Following the sustainability approach, it was decided to manufacture the beams, not only with the standard Portland cement type I, but also with cement type IV with the addition of fly ash, in order to manufacture more sustainable concretes.

The decision to work firstly with small samples and to finish the work with real-scale elements was taken to realize this objective. The experimental methods developed to reach the final objective have been divided into three chapters in this PhD thesis. Each chapter has introduced a different level of scale that has broadened the investigation. The introductory chapters have presented the scope of the research and a full description of the materials and methods used in the development of the thesis.

In the first part (Chapter 4), the work performed on mortar mixes has been presented. Firstly, the interaction of the steel slags with cement type IV was analyzed by manufacturing mixes with different dosages and developing mechanical and durability tests. The mechanical properties displayed an excellent behavior.

Subsequently, the manufacture of self-compacting mortar mixes has been presented. It is essential to obtain a good mortar paste, in order to manufacture self-compacting concretes. Several mortar mixes were manufactured and their fresh properties

analyzed. The hardened properties were also evaluated, achieving strengths of up to 100 MPa, and the mixtures manufactured with EAF slag aggregate displayed superior behavior to mixtures manufactured with natural aggregates. This effect is a consequence of a suitable mortar microstructure, as is evident from the MIP and CAT analyses. Accelerated aging tests were also performed on the self-compacting mortar mixes, demonstrating the innocuous effect of EAF slag.

In the second part (Chapter 5), the studies on pumpable and self-compacting concrete mixes with EAF slag added as aggregate have been presented. An in-depth analysis of the workability of self-compacting mixes has shown the essential need for careful control of the fine fraction and selection of a compatible chemical admixture to attain the required flowability. A numerical simulation of the viscous flux of these self-compacting mixes has been proposed, reporting very acceptable results. The mechanical properties of these concretes indicated good performance and the analysis of some SEM observations of the fracture surfaces on the SCC-EAFS concrete revealed significant features, which help us to understand their structure and mechanical behavior.

An extensive testing regime to assess the durability of these concretes has also been described. Some classical tests, such as freezing-thawing and drying-wetting, were conducted until noteworthy deterioration was appreciated in the mixes. Singular tests, such as immersion in sea water in the tidal zone, and a study on reinforcement corrosion in marine environment, were also performed to evaluate the quality and usefulness of this kind of concrete. The results have demonstrated that EAF slag concretes behave in a satisfactory way in these environments.

In the last part (Chapter 6), the manufacture and performance of real-scale EAF slag reinforced beams has been investigated. These beams were manufactured with pumpable and self-compacting concretes and, for each consistency, cement type I and cement type IV were used for manufacturing different mixes. All the mixes displayed good fresh behavior during the casting period, producing beams without any honeycomb. The flexural behavior of the beams was analyzed and yielded results similar to analytical values calculated with the existing formulation. The long-term deflection of the beams was evaluated and all the beams performed well over the full duration of the test.

Analyzing the general conclusions drawn from this research, it can be stated that the main objective of the thesis has been achieved.

Table of Contents

Table of Contents

Chapter 1:
Preface

1

Preface

1.1. Introduction

An essential component of moving towards the sustainability of the planet and a circular economy is making use of waste as raw materials, an issue in which many researchers and politicians are engaged. Currently, the construction and civil works industry is one of the heaviest consumers of waste materials. These waste materials may come from their own construction and civil works (demolition and construction wastes), from agricultural industries (palm oil fuel ash, bagasse ash, wood waste ash, bamboo leaf ash, corn cob ash, rice husk ash, etc.) and from industrial processes (silica fume, fly ash, steel slags, etc.).

The iron and steelmaking industry is a very important activity for economies all over the world. It consumes a large amount of raw materials and energy: it is estimated that over 5% of global CO_2 emissions is produced by this industry. There are different types of furnaces in use today in the iron and steelmaking industry and each furnace type generates a different type of waste. There are at least eight different wastes that are produced by this sector:

- Ground granulated blast furnace slag (300 to 400 kg per ton of pig iron)
- Cupola furnace slag (60 to 80 kg per ton of cast iron)
- Ladle furnace slag (60 to 80 kg per ton of steel)
- Electric arc furnace slag (150 to 180 kg per ton of steel)
- Basic oxygen furnace slag (120 to 150 kg per ton of steel)