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Cementos portland ternarios elaborados con escoria granulada de alto horno molida y cenizas volantes de carbón: desempeño de resistencia a la compresión

Ternary portland cements made with ground granulated blast-furnace slag and coal fly ash: compressive strength performance

Rosa Abnelia Rivera[a]; Domingo Alfonso Martín[b]; Miguel Ángel Sanjuán[c]

[a]Department of Cement Chemical Testing, LOEMCO. Technical University of Madrid (UPM), Avda. Eric Kandel 0001, LOEMCO Building. South Technological Area "Acedinos". 28906 - GETAFE (Madrid), Spain. rosa.rcornelio@alumnos.upm.es
[b]Lecturer and Associate Director for Economic and Infrastructure Affairs. E.T.S de Ingeniería de Minas. Technical University of Madrid (UPM). C/ Ríos Rosas, 21, 28003 Madrid. domingoalfonso.martin@upm.es
[c]Spanish Institute for Cement and its Applications (IECA), C/ José Abascal, 53, 28003 Madrid, Spain. masanjuan@ieca.es

Resumen-- **Se informó que la producción mundial de cemento Portland fue de 4650 millones de toneladas en 2016. Dicha producción de cemento exige una cantidad significativa de recursos naturales y energía. Además, la producción de una tonelada de cemento Portland emite alrededor de 0,87 toneladas de dióxido de carbono. Este valor se reduciría significativamente al utilizar cementos ternarios elaborados con residuos industriales como escoria granulada de alto horno molida (GGBFS) y cenizas volantes de carbón (CFA). Además, se promueve la economía circular mediante el uso de residuos industriales (GGBFS y CFA) y se aumenta la durabilidad del hormigón en ambientes agresivos. Por el contrario, inducen un retraso en la ganancia de resistencia a la compresión como resultado de la reacción puzolánica. En este trabajo se ensayaron mezclas ternarias de cemento con proporciones GGBFS y CFA (25% y 40%) sobre morteros estándar. En consecuencia, se realizaron medidas de resistencia a la compresión a los 2, 7 y 28 días. Se discutieron las interacciones estadísticas entre GGBFS y CFA en los resultados de resistencia a la compresión de los morteros de cemento Portland ternarios.**

Palabras clave— Cementos ternarios; cenizas volantes de carbón; escoria de alto horno granulada; resistencia a la compresión; sinergia.

Abstract— **Global production of Portland cement was reported to be 4.65 billion tons in 2016. Such cement production demands a significant amount of natural resources and energy. Furthermore, the production of one tonne of Portland cement emits about 0.87 tons of carbon dioxide. This value would be reduced significantly by using ternary cements made with industrial wastes such as ground granulated blast-furnace slag (GGBFS) and coal fly ash (CFA). In addition, circular economy is promoted by using industrial wastes (GGBFS and CFA) and the concrete durability in aggressive environments is increased. By contrast, they induce a delay in the compressive strength gain as result of the pozzolanic reaction. In this paper, ternary cement mixes with GGBFS and CFA proportions (25% and 40%) were tested on standard mortars. Accordingly, compressive strength measures at 2, 7 and 28 days was performed. Statistical interactions between GGBFS and CFA on the compressive strength results of ternary Portland cement mortars were discussed.**

Index Terms— Ternary cements; coal fly ash; granulated blast-furnace slag; compressive strength; synergy.

R.A is with LOEMCO from Universidad Politécnica de Madrid, in Avda. Eric Kandel 0001, LOEMCO Building. South Technological Area "Acedinos". 28906 - GETAFE (Madrid), Spain. D.A. is Lecturer and Associate director for economic and infrastructure affairs from E.T.S. Mines C/ Ríos Rosas, 21, 28003 Madrid. M.A.S is with 3Spanish Institute for Cement and its Applications (IECA), C/ José Abascal, 53, 28003 Madrid, Spain.

I. Introduction

The global production of Portland cement has been reported to be 4.65 billion tons in 2016 (CEMBUREAU, 20107 and is predicted to get by 7 billion tons in 2050. Such cement production demands a significant amount of natural resources and energy, accounting for higher share of CO2 emission. Currently, the production of one tonne of Portland cement emits about 0.87 tons of carbon dioxide. This value would be reduced significantly by using ternary cements. Consequently, clinker replacement is considered as one of the main reductions levers for the cement industry (Sanjuán, 2020). Nowadays, clinker is mostly replaced with industrial wastes such as ground granulated blast-furnace slag and coal fly ash or natural rocks as limestone and natural pozzolans. Also, other constituents include silica fume, artificial pozzolans and so on. Ternary Portland cements (GBFS-CFA-K) are made by mixing clinker (K), ground granulated blast-furnace slag (GGBFS) and coal fly ash (CFA). All of them are well-known constituents in common Portland cements. These blended cements present some environmental advantages: i) reducing the Portland cement clinker (K) in the cement and then, it enhances a lower CO2 emission; ii) circular economy promotion by using industrial wastes (GGBFS and CFA); iii) increasing the concrete durability in aggressive environments such as marine atmosphere. By contrast, they induce a delay in the compressive strength gain as result of the pozzolanic reaction. However, compressive strength at later ages is high.

II. Experimental

A. Materials

In this paper, a Portland cement CEM I 42.5 R according to the European standard EN 197-1:2011 and two cement constituents (ground granulated blast-furnace slag & coal siliceous fly ash) were used to prepare the ternary cements in the laboratory. Mixes given in Table 1 have been tested on standard mortars. Accordingly, compressive strength measures at 2, 7 and 28 days was performed. Ground granulated blast-furnace slag and coal fly ash proportions (25% and 40%) were chosen to perform a statistical analysis

TABLE I
CODES AND PROPORTIONS OF THE TERNARY CEMENTS

Code	Cement (%)	GGBFS (%)	CFA (%)	S-fineness (cm^2/g)
SA0VA0	100	0	0	-
SA25VA25	50	25	25	3489
SA40VA25	35	40	25	3489
SA25VA40	35	25	40	3489
SA40VA40	20	40	40	3489
SB25VA25	50	25	25	4630
SB40VA25	35	40	25	4630
SB25VA40	35	25	40	4630
SB40VA40	20	40	40	4630

B. Compressive strength

The specimens were tested at two, seven or 28 according to the European standard EN 196-1:2016. The average value recorded from six hemi-specimens is taken.

III. Results and discussion

Compressive strength of the ternary cements was determined and almost all of them meet the European standard EN 197-1:2011 requirements (Fig. 1). Mortar made with ternary cements containing 40% GGBFS and 40% CFA (i. e. SA40VA40 and SB40VA40, respectively) does not achieve the lower limit for the 32.5 N compressive strength class (i. e. 16 MPa at 7 days and 32.5 MPa at 28 days), independently of the GGBFS fineness. Accordingly, these ternary cements cannot be used for structural applications. By contrast, they can be used in non-structural uses. The rest of the ternary cements meet the requirements for the 32.5 N compressive strength class. Given that, SA25VA25 and SB25VA25 (25% GBFS and 25% CFA) ternary cements reached the minimum compressive strength result for the 32.5 R compressive strength class (i. e. 10 MPa at 2 days and 32.5 MPa at 28 days).

At 2 and 7 days, both GGBFS (SA & SB) provides similar compressive strengths (Fig. 1). Nevertheless, at 28 days, the performance is different as consequence of the faster pozzolanic reaction and strength gain promoted in the finer GGBFS (SB).

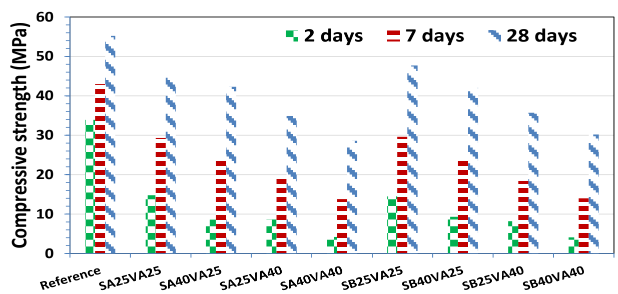

Fig. 1. Compressive strength at 2, 7 and 28 days.

Then, the 28-days compressive strength of ternary cements is increased with the addition of a GGBFS with high fineness in the mixes containing 25–40% GGBFS and 20-40% CFA. However, these values are below the control mix containing only Portland cement. Given that, it could be said that a synergistic effect can be found in ternary cements made with fine GGBFS. This performance can be justified by a denser microstructure found at older ages.

Based on the findings of this paper, it was established that coal fly ash and ground granulated blast-furnace slag in the ternary mortars reduce the compressive strength for all the testing ages. This effect was more evident at the early age compressive strength of mortars with 40% GGBFS and 40% CFA. However, both additions react with the Ca(OH)2 formed during the Portland cement hydration (pozzolanic reaction) and contribute to the increase of the 28-days compressive strength. Furthermore, the higher fineness of GGBFS slightly increases the 28 days compressive strength of ternary cements. Then, the finer the GGBFS, the higher28-days compressive strength.

IV. Conclusions

As a conclusion, it can be said that the proportion for cement:slag:fly ash of 50:25:25 promotes high improvements on 2-, 7- and 28-days compressive strength in comparison with proportions of 35:40:25 and 35:25:40.

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