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Production of durable self-compacting concrete using ladle furnace slag (LFS) as filler material

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Abstract

Ladle furnace slag (LFS) is a by-product of the steel making process. In this paper ladle furnace slag was used as filler material for the production of self-compacting concrete mixtures of different strength classes. Different contents of ladle furnace slag filler, ranging from 45 to 92.5 kg/m^3 were incorporated. The produced concretes were tested in the fresh state for fluidity, passing ability and resistance to segregation and in the hardened state for compressive strength, carbonation and chloride penetration resistance. The test results showed that ladle furnace slag can be used as filler for producing self-compacting concretes with enhanced durability characteristics resulting this way to lower cost environmentally friendly durable concrete mixtures.

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Keywords: selfcompacting concrete; ladle furnace slag; durability

1. Introduction

Self-compacting concrete (SCC) is a novel cement based composite which has the potential to improve the quality of structural elements as well as the quality of the construction procedures. It is widely used in different applications such as ready-mixed concrete and the precast industry because of its many advantages. It can spread

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into place under its own weight and fill restricted sections without the need of mechanical consolidation, improving this way the working environment (reduction of noise in urban environments, reduction of "white finger" syndrome), reducing the manpower need for casting and increasing the speed of construction and the quality of cast structures [1-3]. The basic properties of SCC are the filling ability, the segregation resistance and the passing ability. Rheology of the cement paste is the crucial factor in order to fulfill the above requirements. Self compactibility is strongly connected with the dosage of fine materials. All materials passing the 0.125mm sieve are considered as fine materials. According to the European Guidelines for Self Compacting Concrete [4], the quantity of fine materials per cubic meter of concrete should be in the range of 380- 600 Kg.

The most widely used filler is limestone powder. In Greece, research has shown that industrial by-products have a potential to be used in SCC mixtures replacing either cement or lime filler or both [5-7]. Replacing limestone filler in Greece is rather vital since the production of this material is limited in only two quarries nationally and its high cost makes it unattractive to engineers and contractors.

The present study focuses on the use of ladle furnace slag (LFS), a by-product of the steel production process, as a means for increasing the total powder content in SCC. LFS is a fine material that shows some weak pozzolanic and latent hydraulic properties [8].

2. Experimental program.

Seven different self-compacting concrete mixtures were produced. The mixtures belonged in the strength classes C25/30, C30/37 and C35/45 according to EN206-1 [9]. All concretes were prepared using a Blended Portland Cement, of the type CEM II A-M/42.5N according to European standard EN 197-1. SCCs were prepared and tested in fresh condition according to the specifications of EFNARC [8]. The coarse aggregates consisted of crushed granite with maximum size of 16mm. The fine aggregates used was crushed limestone sand. Limestone filler was used as additional filler materials for the production of reference SCC mixtures of the strength grades C25/30 and C30/37 (SCC25/30-LF and SCC30/37-LF respectively). Ladle furnace slag was used as an alternative filler material replacing aggregates in four SCC mixtures at percentages of 15% and 25% per weight of cement. Ladle furnace slag is a fine material with 100% passing the 96 μm sieve and 95% passing the 45 μm sieve. High range water reducing carboxylic ether polymer admixture was added at different dosages in order to achieve self compactibility in the case of SCCs. The proportions as well as the properties of fresh mixtures are presented for all concretes in Table 1. Self-compacting concretes were prepared and tested according to [8]. Segregation resistance was evaluated the visual analysis of the slump cone test.

Table 1. Mix design characteristics of self-compacting mixtures prepared.

Mixd esign	SCC 25-30 LF	SCC 25-30 LFS 15%	SCC 25-30 LFS 25%	SCC 30-37 LF	SCC 30-37 LFS 15%	SCC 30-37 LFS 25%	SCC 35/45
kg/m^3	SCC 1	SCC 2	SCC 3	SCC 4	SCC 5	SCC 6	SCC 7
CEM II 42,5	300	300	300	370	370	370	430
Coarseaggregates	800	800	800	800	800	800	800
LimestoneSand	910.5	975.5	949.2	901.4	891.5	851.6	933.0
Limestonefiller	120	0	0	50	0	0	0
Ladle furnace slag	0	45	75	0	55.5	92.5	0
Water	180	180	180	170.2	170.2	170.2	180.6
Sup/er	6.70	4.04	4.71	6.39	7.02	9.36	9.46
Retarder	0.45	0.45	0.45	0.56	0.56	0.56	0.65
W/C	0.60	0.60	0.60	0.46	0.46	0.46	0.42
Slump (mm)	780	695	735	710	715	740	715
V-Funnel (sec)	6.4	7.5	7.1	7.9	10.4	9.1	8.4
L-Box (H_1/H_2)	1.00	0.90	0.94	0.84	0.89	0.89	0.85

The specimens prepared were 150 mm (edge) cubes, 60x100 mm and 100X200 cylinders. All specimens were cured for 28 days in a curing chamber (T=20º C, RH>98%). The 150 mm cubes were used for measuring the compressive strength at different ages. Carbonation resistance was measured on 60X100 cylindrical specimens. These small cylinders were initially cured for 3 days in the above mentioned curing chamber. From this age onwards they were placed in the laboratory air environment (relative humidity = 50-60% and temperature =20±2 °C). At the age of 28 days they were moved into the accelerated carbonation chamber (T=20º C, RH=55%, CO_2=1%). Specimens remained in this chamber for 60 days. A second series of specimens was exposed after the age of 3 days in outdoor conditions and remained in unsheltered exposure conditions for 18 months.

Chloride induced resistance of concretes was assessed on cylindrical specimens with a diameter of 100mm and a height of 50 mm formed from the 100X200 cylinders. These specimens were cured as above till the age of 28 days. The chloride diffusion coefficient D_e was then estimated according to the procedure described in NT Built 492 [10] (Figure 1).

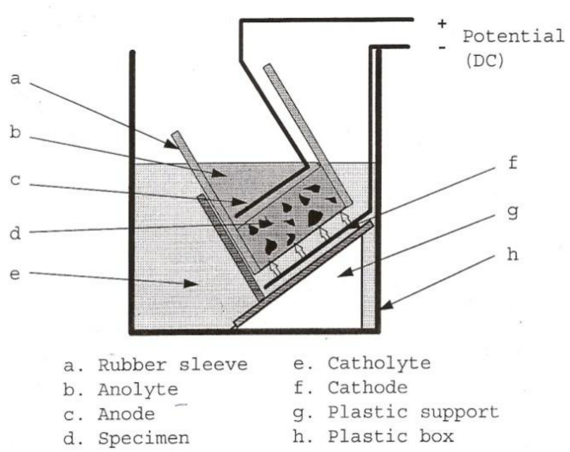

Fig. 1. Test device used for estimation of chloride diffusion coefficient De. (NT Built 492, 1999).

3. Experimental results and discussion

3.1. Influence on the rheological properties of fresh mixtures

Addition of LFS improved the fresh properties of C25/30 SCC mixtures resulting this way to reduction of the superplasticizer amount needed for their production. Segregation resistance of all mixtures was assessed by using the Visual Stability Index (VSI) as described in ASTM-C1611. All mixtures were ranked as VSI=0 and VSI=1 according to this standard, indicating that addition of LFS did not affected negatively the segregation resistance of self-compacting mixtures.

3.2. Compressive strength

Compressive strength was measured for all mixtures at the ages of 2, 7, 28 and 90 days. These values are presented in Table 2.

Table 2. Compressive strength of self-compacting cocnretes (MPa).

(MPa)	SCC 1	SCC 2	SCC 3	SCC 4	SCC 5	SCC 6	SCC 7
fc_2	26.8	23.6	25.7	3.,0	33.3	34.9	39.3
fc_7	32.7	29.0	37.7	44.3	44.3	46.1	45.1
fc_{28}	44.6	44.8	46.9	54.1	55.8	57.5	60.0
fc_{90}	46.0	46.2	49.4	55.6	57.8	61.8	63.1

Compressive strength of all SCC mixtures prepared with LFS addition was increased as compared with the one of reference SCC mixtures of the same grade. C25/30 SCC mixtures produced with 25%LFS performed an increase in 28 days compressive strength of 2.3 MPa (5.1% of the strength measured on reference SCC produced with limestone filler). The strength difference was slightly increased up to 3.4 MPa (7.4%) at the age of 90 days. Setien et al [8] also reported that ladle furnace slag performs cementitious hydraulic properties. Anastasiou et al [11] concluded that LFS had a positive effect on strength development concerning 28-days and 120-days compressive strength. The researchers produced self-compacting concretes with addition of ladle furnace slag between 60 and 120 Kg/m^3. In this research ladle furnace slag was added at smaller dosages in SCC25/30 mixtures, thus the strength gain was smaller. Strength gain percentage was higher (6.3% and 11.15% at the ages of 28 and 90 days respectively) in SCC6 mixture where ladle furnace slag dosage was increased up to 92.5 Kg/m^3. It is also noticeable that in this case compressive strength started to increase from the age of 2 days while the value measured at the age of 28 days was very close to the one of the SCC35/45 mixture, enabling this way this mixture to be graded as a C35/45 concrete.

3.3. Carbonation depth

Carbonation depth was measured by spraying the fresh broken surfaces of concretes with a phenolopthalein indicator, according to the procedure described in EN 14630 Standard [12]. The carbonation depth of all mixtures is presented in Table 3 and plotted on Figure 2.

Table 3. Carbonation depth of self-compacting concretes prepared.

Carbonation (mm)	SCC 1	SCC 2	SCC 3	SCC 4	SCC 5	SCC 6	SCC 7
Natural (18 months)	3.3	2.9	2.7	2.1	1.5	1.7	1.5
Accelerated	10.6	10	7.9	3.9	3.4	3	2.6

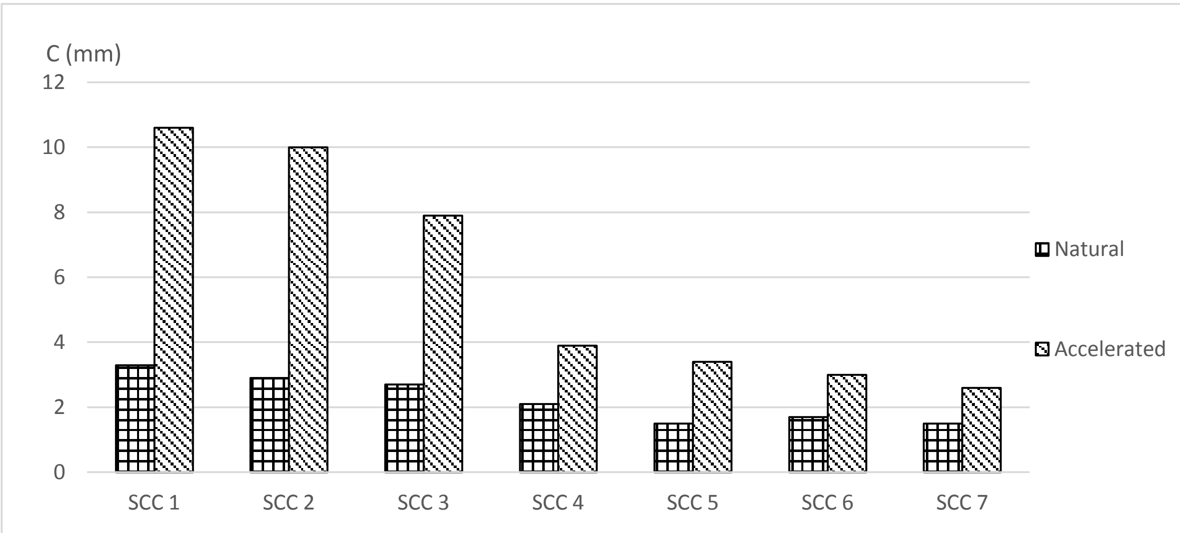

Fig. 2. Carbonation depth of self-compacting concretes.

Addition of ladle furnace slag increased the carbonation resistance of all SCC mixtures prepared since the carbonation depths were decreased both in natural and accelerated exposed specimens [Fig. 2]. It was pointed out [13] that carbonation resistance of self-compacting concretes is strictly depending on the type and dosage of the material used as filler. Papayianni and Anastasiou [14] reported that mixtures produced with ladle furnace slag as binders and EAF slag as aggregates are impermeable with improved microstructure and low porosity. These findings were verified in this research since addition of LFS decreased the carbonation depth of SCC mixtures by 25% (SCC25/30 concretes) and 28% (SCC30/37 concretes) as compared with reference SCC mixtures produced with limestone filler. It is also essential to notice that when LFS was used in high dosage -25% of the weight of the cement- the carbonation depth of naturally exposed specimens after 18 months was reduced down to the value measured on higher strength reference SCC mixtures. Research is still in progress in order to evaluate the influence of LFS on the carbonation coefficient of SCC mixtures and finally on the service life of reinforced concrete structures produced with LFS containing concretes.

3.4. Chloride diffusion coefficient

The Chloride diffusion coefficient values D_e measured according to NT Built 492 are presented for all mixtures in Table 4.

Table 4. Chloride diffusion coefficients De (10^{-12} m^2/s) of self-compacting concretes prepared.

	SCC 1	SCC 2	SCC 3	SCC 4	SCC 5	SCC 6	SCC 7
De ($x10^{-12} m^2/s$)	19.5	15.5	15.1	8.7	7	5.9	6

Chloride induced corrosion resistance was also improved when SCC mixtures were produced with LFS instead of limestone filler. Chloride diffusion coefficients De of self-compacting concretes prepared was reduced for SCCs containing LFS (Table 4). It is once again noticeable that SCC30/37 LFS25% mixture performs De value equal to the one measured on SCC35/45 specimens. Papayianni and Anastasiou [14] also reported that chloride induced corrosion of LFS produced concretes was improved.

4. Conclusions

Ladle furnace slag may be used as filler material for the production of self-compacting concretes. Addition of LFS improved the fresh properties of SCC mixtures resulting this way to reduction of the superplasticizer amount needed in C25/30 SCC mixtures.

Compressive strength of SCC25/30 mixtures was slightly increased at later ages when LFS was used. The effect on strength increase was more significant in SCC30/37 mixtures where higher dosages of LFS were added. In this case LFS produced mixtures performed higher compressive strength than reference SCC even from the age of 2 days while the 28-day strength of SCC mixture produced with 25% LFS makes possible its classification in an upper strength class.

Durability properties of LFS SCCs were improved especially in mixtures produced with higher amount of LFS and lower w/c ratio. Both carbonation and chloride resistance were increased. This increase was more essential in SCC30/37 mixture produced with 25%LFS where both durability indicators found to be equal with the values measured on SCC35/45 mixture.

Further research is now in progress in order to quantify the effect of LFS on the durability of SCC as well as the long term performance and stability of the produced mixtures. The results will further demonstrate the possibility to use LFS for the production of high performance durable and environmentally friendly self-compacting concrete mixtures.

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