Proceedings of the EUROCOALASH 2012 Conference,
Thessaloniki Greece, September 25-27 2012
http:// www.evipar.org/

Development of ferrocement matrix by using calcareous fly ash and ladle furnace slag as pozzolanic admixtures

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Abstract

Ferrocement is defined as reinforced mortar with multiple layers of steel mesh encapsulated in mortar matrix. It is widely used for housing units, flat or corrugated roofing sheets as well as other structural components. Ferrocement seems to be an alternative for roofing elements supporting photovoltaic cells. Mortar is usually injected and therefore, fluidity of it is the important criteria for the design of the mortar mixture apart from the required strength. According to ACI 549-1R5, the mortar mixture is a rich in cement mixture in which pozzolanic admixtures are added to replace part of fine aggregates. In addition, synthetic fibres may be used to increase toughness and contribute to elongation of service life of ferrocement applications. In this paper, the experimental work concerning the development of ferrocement matrix with addition of fly ash, ladle furnace slag and synthetic fibers is presented. The two pozzolanic admixtures were added at 10, 15 and 20% of cement mass while the polypropylene fibres content was 0.7, 0.8 and 0.9% by volume of the total mixture. Super plasticizer of carboxylic origin was also used. The properties of fresh mortar measured were apparent specific density and plasticity immediately and one hour after mixing. The hardened mortar matrix was tested by determining characteristic compressive strength f_c (by using cylindrical 15x30cm specimens) as well as flexural strength and static modulus of elasticity at 28-d age. Additionally, fracture energy was measured according to JCI-S-001-2003 Standard. The 28-d age early shrinkage deformation of concrete matrix with and without fibers was also measured. Based on results, it seems that fly ash addition contributes to 23% strength increase in comparison to control plain cement mixture. A characteristic compressive strength of 50 MPa is achieved in mixtures with 10 and 15% fly ash by mass of cement of the same level of fluidity with the control mixture. Fracture energy is also higher while early shrinkage is reduced. The addition of ladle furnace slag influences very positively the plasticity while the 28-d strength ranges around the control mixture strength.

Keywords: ferrocement, calcareous fly ash, ladle furnace slag, synthetic fibers, compressive strength

1 Introduction

According to ACI 549.1R [1], ferrocement is a cement product that could be defined as reinforced mortar with multiple layers of steel mesh (often galvanized) encapsulated in the mortar matrix. It is used for many structural components such as housing units, water tanks, grain silos, flat or corrugated roofing sheet and it seems to be a good alternative for roofing elements supporting photovoltaic cells, providing convenience and in short time constructional solutions. In this case, the ferrocement could be applied by injection contributing to bonding of the matrix with mesh. This process requires mortar mixture of high fluidity which will last a logical period of time to finish application. A robust self compacting mortar, rich in cementitious materials which fulfill strength and durability requirements imposed in each application could be used as ferrocement matrix.

Since this matrix is prone to shrinkage deformations including autogeneous shrinkage (which is favored in rich in cement and low water/cement ratios mixtures), any improvement of the matrix to this direction will be beneficial to its service life.

One of the most important factors affecting the durability of ferrocement is the corrosion of wire meshes. This phenomenon is magnified in corrosive environments. The corrosion of the wires leads to a reduction in diameter, loss of effective strength and deterioration of the bond between the matrix and the reinforcement [2]. Even though the measures to insure durability on conventional reinforced concrete can also be applied to ferrocement, the thin coating of the metallic mesh, the large surface area of the structure and the extreme environmental conditions that ferrocement is usually subjected makes it prone to deterioration [3]. For this reason, the wire mesh reinforcement used in ferrocement is also available to galvanized form. Other measures to improve the corrosion resistance of ferrocement are the use of mineral admixtures in concrete such as fly ash, blast furnace slag or silica fume [2], [4], [5] or low water-to-cement (w/c) ratio [6]. In ACI 549 1R-2, the use of pozzolanic admixtures for a part replacement of fine aggregates as well as of synthetic fibers is also recommended.

The scope of the research work done was to improve the ferrocement matrix by adding supplementary cementitious materials as substitute for cement and fines and also polypropylene fibers to increase toughness of the matrix. Greek calcareous fly ash of relative high lime content and ladle furnace slag were used as cementitious materials since they had been proven effective constituents of self compacting mixtures in reducing early shrinkage and increasing fluidity respectively [7, 8].

2 Experimental program

River sand of 2.650 gr/cm³ density tested according to ASTM C 128-01 (Standard Test Method for Density, Relative Density and Absorption of Fine Aggregate) and 3% moisture content according to ASTM C 566-97 (Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying) was used as aggregate. The nominal maximum aggregate size of river sand was 2 mm. Type I 52.5N cement was used, following the ASTM C150 or ASTM C595 for conventional concrete, as proposed by ACI Committee 549. The two pozzolanic admixtures that were added in the mixtures were either Fly Ash (FA) or Ladle Furnace Slag (LFS). Fly ash, with 9-10% CaO_{free} and 5-6% SO3, is coming from a lignite fire power plant while ladle furnace slag is originated from a steel industry. The retained material at the 45μm sieve (R45) was 38.5% for FA and 21.0% for LFS. Corrugated polypropylene fibres of 50mm length and 0.8mm diameter and super plasticizer of carboxylic origin (Glenium SKY 645) were also added in the mixtures.

The characteristics of the 14 mixtures that were prepared in the laboratory are presented in Table 1. In half of the mixtures, polypropylene fibers were used and the fiber volume content was 0.7, 0.8 or 0.9% by volume of the total mixture. Mixture C and fibrous mixture CF are the control mixtures in which no pozzolanic admixtures were added.

Table 1. Basic characteristics of ferrocement mixtures produced in the laboratory

Control ferrocement mixtures C, CF and mixtures with FA								
	C	CF	CA1	CAF1	CA2	CAF2	CA3	CAF3
Cement I 52,5N (kg/m³)	680	660	660	660	660	660	660	660
LFS/ Cement ratio	-	-	-	-	-	-	-	-
FA/ Cement ratio	-	-	0.10	0.10	0.15	0.15	0.20	0.20
Water/Cement ratio	0.35	0.35	0.36	0.36	0.37	0.37	0.38	0.38
Fiber volume content (%)	-	0,8	-	0,7	-	0,8	-	0,9
Plasticizer/cementitious (%)	2	2	2	2	2	2	2	2
Ferrocement mixtures with LFS								
	CS1	CSF1	CS2	CSF2	CS3	CSF3		
Cement I 52,5N (kg/m³)	660	660	660	660	660	660		
LFS/ Cement ratio	0.10	0.10	0.15	0.15	0.20	0.20		
FA/ Cement ratio	-	-	-	-	-	-		
Water/Cement ratio	0.35	0.35	0.35	0.35	0.39	0.39		
Fiber volume content (%)	-	0.7	-	0.8	-	0.9		
Plasticizer/cementitious (%)	1.0	1.5	1.5	1.5	2.0	2.0		

The two by-products, FA and LFS, were added at 10, 15 or 20% of the cement mass in plain and fibrous ferrocement mixtures. The moisture of the aggregates was taken into account so the amount of water was modified properly. The proportions of all the mixtures are shown in Table 2.

Table 2. Proportions of ferrocement mixtures (kg/m³)

Control ferrocement mixtures C, CF and mixtures with FA								
	C	CF	CA1	CAF1	CA2	CAF2	CA3	CAF3
Cement I 52,5N	680	680	660	660	660	660	660	660
Water	245	245	261	261	281	281	301	301
FA	-	-	66	66	99	99	132	132
River sand	1360	1360	1320	1320	1518	1518	1584	1584
Glenium SKY 645	13.60	13.60	14.52	14.52	15.18	15.18	15.84	15.84
Polypropylene fibres	-	7.20	-	6.30	-	7.20	-	8.10
Ferrocement mixtures with LFS								
	CS1	CSF1	CS2	CSF2	CS3	CSF3		
Cement I 52,5N	660	660	660	660	660	660		
Water	254	254	266	266	309	309		
LFS	66	66	99	99	132	132		
River sand	1320	1320	1518	1518	1584	1584		
Glenium SKY 645	7.26	10.89	11.39	11.39	15.84	15.84		
Polypropylene fibres	-	6.30	-	7.20	-	8.10		

The apparent specific densities of fresh ferrocement mixtures are shown in Fig. 1.The measurements for fluidity of the mixtures immediately and 1h after mixing are given in Table 3.

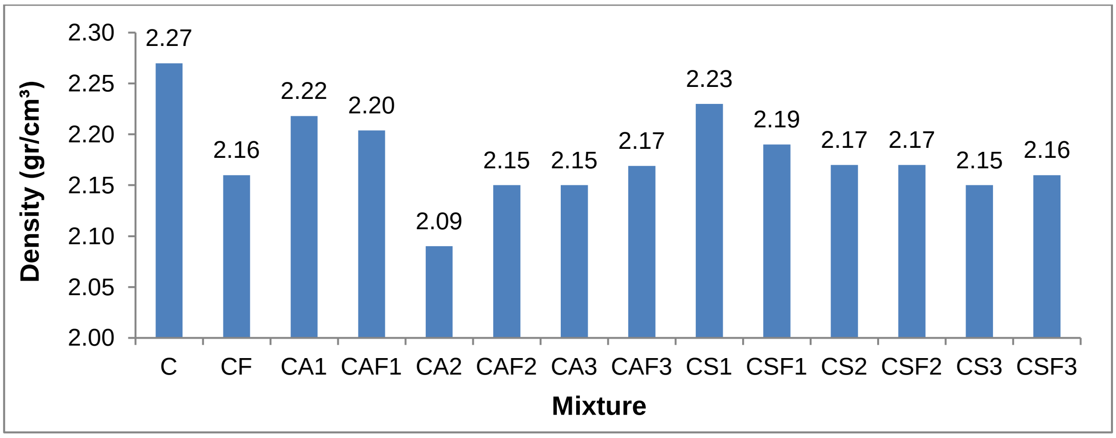

Fig. 1 Density of fresh ferrocement

Table 3. Plasticity of fresh mortar according to ASTM C 1611-09 [9]

Control ferrocement mixtures C, CF and mixtures with FA								
	C	CF	CA1	CAF1	CA2	CAF2	CA3	CAF3
Immediately after mixing								
Time for 50cm expansion (sec)	19	14	20	25	7	-	-	-
Final expansion (cm)	52	52	50	56	51	40	44	40
1 hour after mixing								
Time for 50cm expansion (sec)	22	-	-	50	9	-	-	-
Final expansion (cm)	50	48	47	50	48	30	38	37

Ferrocement mixtures with LFS						
	CS1	CSF1	CS2	CSF2	CS3	CSF3
Immediately after mixing						
Time for 50cm expansion (sec)	10	3	7	14	3	7
Final expansion (cm)	54	75	59	54	65	60
1 hour after mixing						
Time for 50cm expansion (sec)	11	3	13	60	7	14
Final expansion (cm)	50	72	55	50	55	54

No compaction was applied during the casting since the fluidity of the mixtures was sufficient. The specimens cast for determining the properties of each ferrocement mixture were six cylinders 150x300 mm (for measuring the characteristic compressive strength and modulus of elasticity), two beams 150x150x550 mm (for measuring the flexural strength) and two beams 100x100x400 mm to measure the early shrinkage deformation. Additionally, the flexural behavior of notched beams was tested by recording load-Crack Mouth Opening Displacement (CMOD) curves (Fig. 2). From the analysis of these curves, the toughness levels were estimated by calculating the Fracture Energy G_f according to JCI-S-001-2003 Standard [10]. All specimens were cured at 20° C and 95% RH for 28 days.

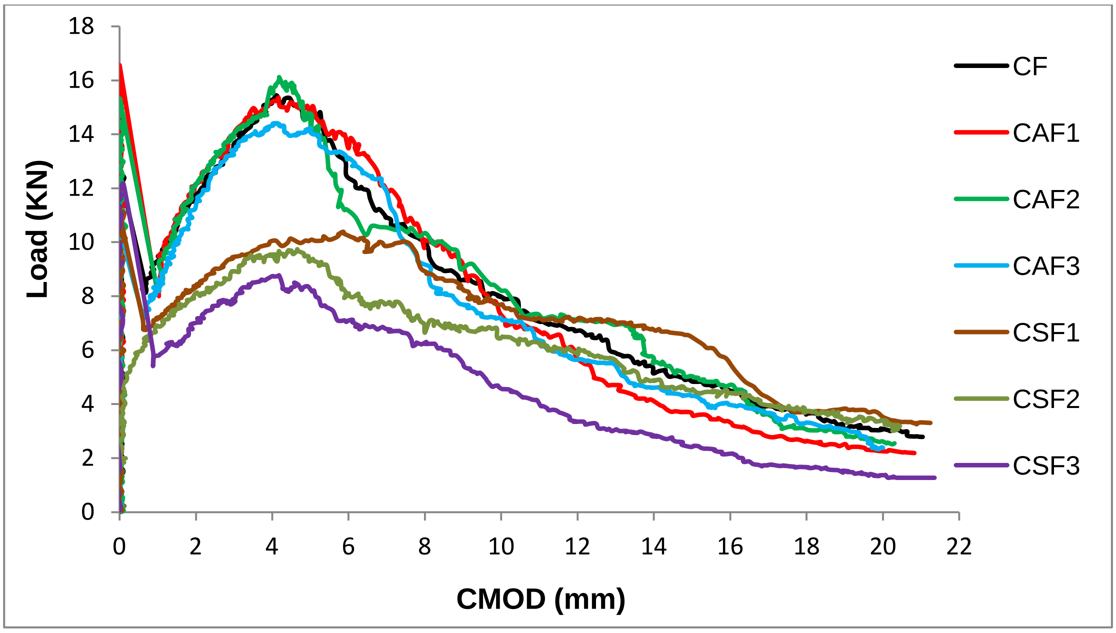

Fig. 2 Load-CMOD curves of all the fibrous mixtures

3 Results and discussion

The properties of hardened ferrocement matrices are shown in Table 4 and Fig 3-5. Regarding 28-d compressive strength, for mixtures with up to 0.20 FA/cement ratio the same or higher level of strength has been achieved in comparison to control mixtures C (without fibers) and CF (with fibers).

Table 4. Properties of hardened matrix

Control ferrocement mixtures C, CF and mixtures with FA								
Properties	C	CF	CA1	CAF1	CA2	CAF2	CA3	CAF3
Density (kg/m³)	2190	2140	2178	2169	2140	2100	2120	2050
Flexural strength (MPa)	4.23	4.51	4.25	4.54	3.08	3.88	2.73	3.89
Modulus of elasticity (GPa)	24.63	24.26	24.43	23.21	21.50	20.01	19.78	20.61
28-d early shrinkage (μstrain)	1150	1100	875	850	788	843	775	745

Ferrocement mixtures with LFS						
Properties	CS1	CSF1	CS2	CSF2	CS3	CSF3
Density (kg/m³)	2180	2150	2120	2150	2140	2150
Flexural strength (MPa)	3.54	4.17	3.35	4.00	2.96	3.11
Modulus of elasticity (GPa)	23.10	24.12	22.00	27.94	18.74	20.25
28-d early shrinkage (μstrain)	875	825	850	825	775	763

Mixture CAF1 presented the best results, reaching 53.75 MPa, with fiber volume content 0.7% and FA/cement ratio 0.10. Flexural strength (MPa) and Modulus of Elasticity (GPa) follow in general the mode of compressive strength. However, it could be said that as the content of fly ash increases, these mechanical characteristics are shifted to lower values in relation to control.

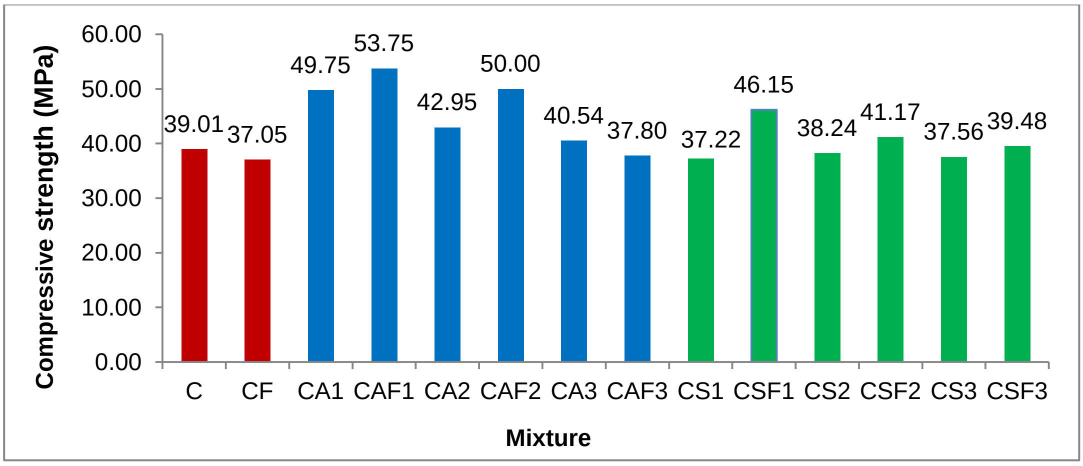

Fig. 3 Compressive strength of all the ferrocement mixtures

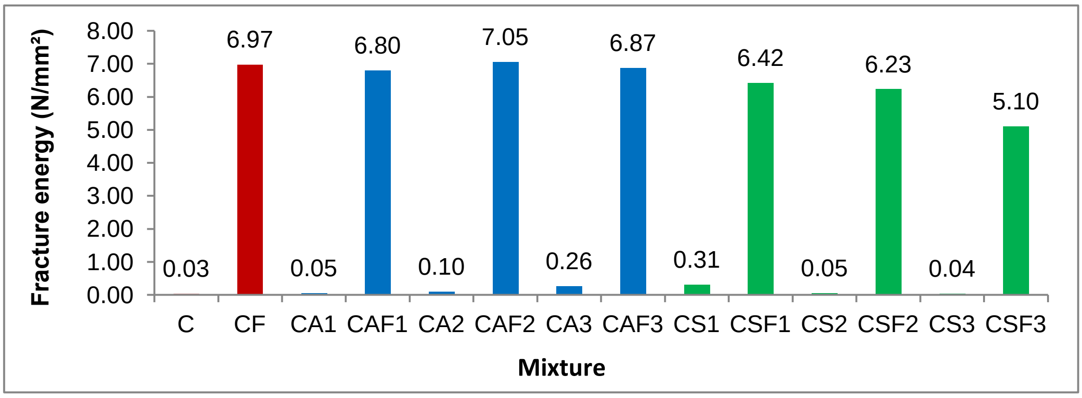

Fig 4. Fracture Energy of all the mixtures as obtained from the Load-CMOD curves

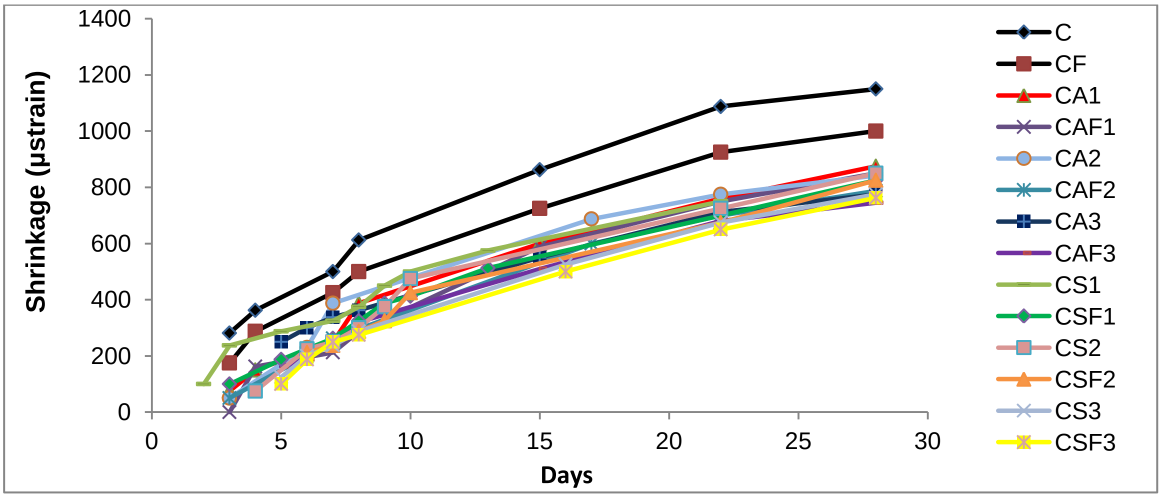

Fig. 5 Early shrinkage deformation of all the mixtures

Fracture energy values of mixtures with fly ash are also comparable to those of control mixtures. Considering early shrinkage deformation, they are also significantly lower in mixtures with fly ash, even in those without fibers, as shown in Fig. 5. It is obvious that fly ash additions improve the ferrocement matrix. However, the fluidity for FA/cement ratios higher than 0.15 is reduced although superplasticizers have been used. This is a negative phenomenon especially in the case of mixtures with fibers. When LFS is used from LFS/cement ratio 0.10 to 0.20, the 28-d strength development is lower or of the same level compared to control mixtures. Fracture energy values follow the strength pattern and early shrinkage deformations are lower than those of control mixtures. Flexural strength and Modulus of Elasticity are not developed with the same rate with compressive strength and lower to control ferrocement. The best composition is CSF1 with LFS/cement ratio 0.1 and 0.7% fiber volume content. What is very advantageous is the reduction of time for initial fluidity (measured by expansion according to relative EFNARC regulative frame) and the higher final expansion (cm) 1 hour after mixing.

The pros and cons of FA and LFS addition to ferrocement mixtures seem to limit their addition towards low FA or LFS/cement ratios such as 0.10 and 0.15. Comparing the effectiveness of fiber volume content, it seems that the 0.7 and 0.8% presented the best results in both series of mixtures with FA and LFS. Regarding durability of ferrocement, it should be checked especially to resistance to chloride ingress and corrosion of the embodied mesh. To this direction, a new research program will follow. However, according to many researchers [11, 12, 13], it is expected that modified with FA and LFS mixtures will exhibit better to control performance.

Acknowledgements

TITAN cement industry is acknowledged for the free supply of cement used in this work. Thanks are also expressed to students of Civil Engineering of AUTH participating in the experimental work under author's supervision.

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