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FLY ASH PORTLAND CEMENT BASED MORTAR FOR POST-INSTALLED REBARS IN HARDENED CONCRETE

BY

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Abstract. This paper presents a study of performance evaluation of fluid cement-based mortars containing fly ash used as structural bonding material for fixing reinforcing steel bars in hardened concrete. A series of standardized tests were performed during the experimental setup with the objective of assessing the performance of the mortars in terms of fluidity, cohesiveness and early age strength. This experimental work also investigates the strength at 24 hours, 7 and 28 days of the fluid mortars used as bonding material. The bond strength of the rebars at 7 days is assessed by pull-out tests. The study results were positive showing that it is feasible to anchor resistance steel rebars in hardened concrete of low and medium strength.

Key words: fly ash; Portland cement; rebars; anchoring mortar; bond; fine sand.

1. Introduction

A cementitious mortar intended for use in structural anchoring should meet several performance criteria concerning the initial properties as

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flowability, cohesiveness, stability and the final properties as strength, rigidity, deformation volume and durability. A right flowability and cohesiveness assures the placing of mortar into a hole of 20 to 30 mm diameter and of 20 times the rebar diameter deep, at least. High values for the compressive strength and the elasticity modulus assures a well bond strength and enough rigidity, where the rebar is pulled-out from the hardened concrete.

2. Objectives

The main objective is to develop a performance anchoring material using ordinary blended cements available into the European market. Particularly in this study fly ash is the involved supplementary cementitious material. The study evaluated the workability and mechanical properties of the developed cementitious mix. The study evaluated the bond strength of steel reinforcing bars (rebars) post-installed with the developed cementitious mix.

3. Performance Requirements for Structural Anchoring Mortars

The Part 6 of the SREN 1504 states that to grout reinforcing steel bars in concrete structures, the following products are typically used: cement based materials, synthetic resins or a mixture of these in either fluid or thixotropic consistency.

3.1. Strength of Hardened Mortar

The anchoring mortar could be considered an anchoring product which gives sufficient structural behaviour for and embedded rebar into hardened concrete. According to SREN 1504-3 this anchoring product can be classified as a structural repair mortar. According to Table 3 of SREN 1504-3 the cementitious repair products are divided into two groups, structural and non-structural. It is considered that to withstand properly to the pull-out force the anchoring mortar should fulfil at least the requirements for a R4 structural class repair product. That means a compressive strength of at least 45 MPa, adhesive bond greater than 2 MPa and an elasticity modulus higher than 20 GPa.

3.2. Rigidity of Hardened Mortar

Part 6 of the SREN 1504 European standard specifies requirements for the displacement performance of cementitious products to be used for the anchoring of reinforcing steel as used for structural strengthening to ensure the continuity of reinforced concrete structures. Thus, the maximum displacement of the loaded end of the rebar is 0.6 mm at a conventional load of 75 KN, considering geometrical installation characteristics specified in SREN 1881, *i.e.* Φ16 mm steel rebar embedded 150 mm into a hole of 30 mm diameter. That means, according to the uniform stress bond model, the bond stress level is approximate 9.94 MPa. For an equal stress level, the correspondent control forces of the others installation characteristics can be calculated.

4. Materials and Methods

The used anchoring mortar is a mixture of Portland-composite cement, aggregate, water and chemical admixture. The blended cement used in this study was the Portland-composite cement CEM II/A-V 42.5 which includes 6...20% fly ash grounded with the Portland clinker at manufacturing.

The aggregate consist of sand, which was divided into two categories as coarse and fine sand. The natural river sand, which is considered round and less rough, was used. In Table 1 the particle size of coarse and fine aggregate is given. The maximum size coarse aggregate (MSA) was 2 mm. The used chemical admixture is the polycarboxylate superplasticizer (PCE).

The involved methods in this study concern with designing of the mixture and assessment of the fresh properties and the hardened properties of anchoring mortar. According to SREN 1504-1 the anchoring mortar based on Portland cement was included into the repair products category for concrete structures. Therefore, the methods to determine the initial and final characteristics was the methods indicated in SREN 1504. For bond strength, the method, which is indicated by EOTA TR023,was used. Some recommendations given in SREN 1881 was followed, too, for the bond strength.

Table 1
Size of the Coarse and the Fine Sand

Fine	0.2...0.4 mm
	0.4...0.63 mm
	0.63...0.8 mm
Coarse	1.0...2.0 mm

4.1. Material Properties

The fly ash admixture has a particle size very to the cement clinker but the shape is round, and thus the flowability of the mixture is enhanced. Besides when the fly ash replaces the cement clinker the required chemical admixture amount is reduced. Therefore, for a such mixture, replacing cement clinker with fly ash, the yield stress τo is reduced and plastic viscosity is increased. The grounded fly ash of the CEM II/A-V composite cement is silicoaluminous (Class F), according to the declaration of conformity.

HRWR admixtures are the most important chemical admixtures used in the production of flowing concrete. Their primary function is to disperse cement particles. By doing so, they provide high levels of fluidity and lowering the potential for segregation and bleeding. Minimizing water content by using of HRWR the viscosity of the mixture which contains fly ash is adequate.

4.2. Design of the Mixture

Because of the required properties of the anchoring mortar, see Table 2, which are similar with those of a concrete of strength class at least C45/55, the used design method of the mixture contains many elements of the design method for the ordinary concrete. In fact this mixture can be seen as a micro-concrete mixture because the maximum aggregate size (MSA) is 2 mm.

Both the Dreux-Gorisse and absolute volume method were used to design the mixture of mortar . The aimed properties of anchoring mortar are given in Table 2.

Table 2
Aimed Properties of Anchoring Mortar

Consistence	≥ 220 mm (flow table)	
Cohesivness	Good	
Compressive strength	7 days	≥ 45 MPa
	28 days	≥ 50 MPa
Tensile strength	≥4 MPa	
Bond strength	≥16 MPa	

The known data about constituent materials are given in Table 3. The blended cement was supplied from Medgidia cement plant of the Lafarge company.

Table 3
Properties of the Constituent Materials

Cement	CEM II/A-V 42.5	
	Standard Strength	52.3 MPa
	Absolute density	3.0 kg/dm^3
Aggregate	Maximum size MSA	2.0 mm
	Bulk loose density	1.43 kg/dm^3
	Absolute density	2.65 kg/dm^3
Chemical admixture	Superplasticizer HWRA	
	1% of composite cement	

The method Dreux-Gorrise, called also the French method, is basically of an empirical nature, unlike the previous Faury's method, which was based upon Caquot's optimum grading theory (Dreux, 1998). Dreux made an extensive enquiry to collect data about satisfactory concretes. More about Dreux-Gorisse method by de Larrard, (1999).

The designing steps of anchoring mortar mixture are:

a) determination of the target compressive strength, see Table 2;

b) selection of the fresh concrete consistency (fluid consistency);

c) selection of the maximum size of aggregate (MSA), see Table 2;

d) calculate the water/cement ratio using the Bolomey's equation.

This equation incorporates the cement strength plus an adjustable aggregate factor.

e) calculate the cement dosage using a nomograph, as a function of cement/water ratio and slump.

At this step the nomograpf given by authors is useless for this study, since is limited to a cement dosage of 400 kg/m^3. Therefore, a conversion chart, claimed by Cement Concrete Association was used (Neville, 2003). The chart converts the cement/aggregate ratio into cement dosage based on the water/cement ratio. In order to find out an estimated value of the cement/aggregate ratio, which provides a great workability to the mixture some trial tests were performed. It is known that the greater the volume of paste of the mixture the greater is the workability. Some trial test revealed that for cement/aggregate ratio smaller than 2.5 the workability significantly increases. Based on this data the Cement Concrete Association's chart reveals that the minimum cement dosage is 600 kg/m^3, for aggregate with specific gravity 2.6 kg/m^3 and a cement/aggregate ratio between 2 and 2.5.

f) calculate the water content.

It is calculated from the knowledge of cement content and cement/water ratio. At this step, a correction can be made concerning to maximum size of aggregate MSA (the water content increases when MSA decreases). Therefore, the amount of water was increased at least with 15% considering that MSA is 2.0 mm based on information provided by Dreux (de Larrard, 1999).

g) calculate of the aggregate dosage. The absolute volume method was used to calculate the dosage.

Sand grading was carried out based on a specific discontinuous distribution shape developed by laborator studies. A discontinuous granular shape was adopted to increase the packing density of the aggregate by approaching the particle of coarse sand. Also the percent of coarse sand was increased to increase fluidity for the same amount of water. The negative effect induced by a discontinuous granular shape is compensated by a greater dosage of cement resulted from the design of the mix

To avoid the segregation due to an increased amount of chemical admixture, a constant 1% of superplasticizer HWRA of the cement dosage was considered. Therefore, the required adjustments concerning to workability, see

Table 2, were made by adjusting the cement dosage for a constant w/c ratio. In Table 4 the mix proportions, by weight of cement, are given.

Table 4
Mortar Mix Proportion (*Weight of Cement*)

Mix	Cement	Aggregate	Water	HRWA
1	1	2.18	0.36	0.01
2	1	2.16	0.38	0.01

4.3. Test Method for the Fresh Properties

The flow table method based on the indication given by SREN 13395-1 and SREN 1015-3 was used to assess the workability (Fig. 1).

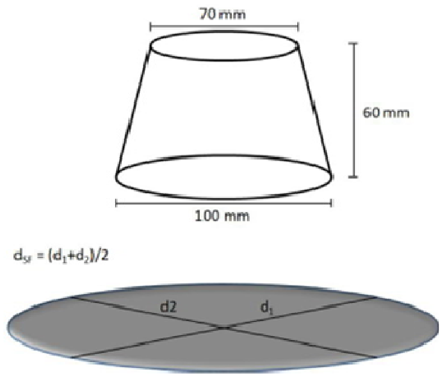

Fig. 1 – The used flow table method, after SREN 1015-3.

4.4. Test Methods of the Strength Properties

To assess the strength of hardened mortar, the method given in SREN 12190, which is based on the method used in SREN 196-1, was applied. The specimen involved into the experimental setup was the 40 × 40 × 160 mm prism.

Hydraulic testing machines were used to perform the tests. A control force testing machine with the maximum capacity of 0.1 MN (100 KN) and three scale of assessment of the force was used to perform the bending of the specimen. The used maximum force scale was 0.02 MN (20 KN). The precission on this scale is 10 N. To test in compression the specimens, a testing machine manufactured by Technotest, 2006 year of fabrication, with the maximum capacity of 3 MN was used. The applied rate of loading was 0.75 MPa/sec. The test in compression of mortars was performed using steel plates (40 × 40 mm) applied on the end prism. The specimens were cured in water and the tests in compression were conducted to ages of 3, 7 and 28 days. The results are reported as an average of six specimens.

4.5. Test Methods for Deformation

The elasticity modulus is an important characteristic of the material. The method emphasised by SREN 13412 was used to assess the elasticity modulus of hardened mortar. The test in compression was performed on mortar prism (40 × 40 × 160 mm) and the secant modulus was determined according to indications given in SREN 13412.

Drying shrinkage is caused by loss of moisture during curing. Shrinkage can lead to the formation of cracks, which may affect the long-term performance of mortar. The method emphasised by SREN 12617-4 was used to assess the linear dry shrinkage of hardened mortar. The method involves preparing of mortar prism specimen, curing one day into the mold and afterwards measuring daily length shortenings during 55 days by means of a device of 0.001 mm precission.

4.6. Test Method of the Bond Strength

The bond strength of the rebars was determined based on the information given in EOTA TR023 and SREN 1881. Both standards are limited to reinforcing steel bars designed in accordance with SREN 1992-1-1. Many tests provided by Part5 of ETAG 001, which are required for usual bonded anchors, can be omitted because the tests will only prove that post-installed rebar connections have a comparable behaviour as cast-in-place rebar connections under different influences. Therefore, only tension load can be transferred to cast-in-place rebar connections according to EC2, shear on the rebars will not be considered (TR023, 2006).

The tests are performed in non-cracked concrete with deformed rebars, that have properties according to Annex C of EC2 with f_{yk} greater than500 MPa and the related rib area f_R between 0.05 and 0.10.

The confined pull-out test is recommended by TR023 for rebars (Fig. 2). In confined test the concrete cone failure is eliminated by the transferring the reaction force close to the anchor into the concrete.

The developed tension test rig used at tests is given in Fig. 3. The specimens were concrete blocks of 300 × 300 × 250 mm. Rebars (Φ14 mm) of BST500 steel were embedded in the specimens. The embedment length was equal to 10Φ and 7Φ. The former embedment length is the minimum anchorage length provided by EC2 and the last was required in test to get the maximum bond strength f_b.

Series of five specimens were involved into the test. The confined pull-out test were performed according to ETAG001 Part5 recommendations. The test was performed in load control and the pull-out load was progressively increased in such away that the peak load occured after 1 to 3 min. from start time (EOTA ETAG001, 2002). A steel plate of 8mm thick with a hole of 38 mm diameter in the centroid was placed between steel test rig and the concrete specimen to increase the concrete confined effect.

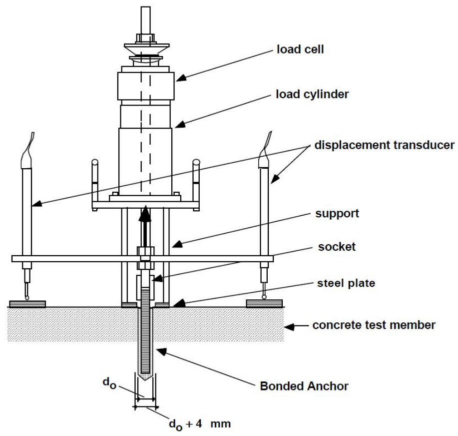

Fig. 2 – Example of a tension test rig for confined tests according to TR023 (EOTA ETAG001, 2002).

a *b*

Fig. 3 – Developed tension test rig for confined tests: *a* – threaded gripping system of the rebar end; *b* – barrel and wedge gripping system of the rebar end.

5. Assessing of the Post Installed Rebars

Based on information provided by EOTA TR023, in general, it shall be shown by the test that the post-installed rebar system can develop the same design values of the bond resistance with the same safety margin as cast-in-place rebars according to EC2 (SREN 1015-3). In the Table 5 the required bond strength for post-installed rebars in hardened concrete are given, according to TR023. It can be seen in Table 5 that the required bond strength for post-installed rebars is at least four times greater than the design values provided by EC2 for pre-installed rebars.

Table 5

Concrete strength class	Design values of the ultimate bond strength according to EC2 for good bond conditions in MPa	Required bond strength for post-installed rebars according to TR023 MPa
C12/15	1.6	7.1
C16/20	2.0	8.6
C20/25	2.3	10.0
C25/30	2.7	11.6
C30/37	3.0	13.1
C35/45	3.4	14.5
C40/50	3.7	15.9
C45/55	4.0	17.2
C50/60	4.3	18.4

5.1. Assessing of the Bond Strength

According to EOTA TR2, based on the results of the pul-out tests the average bond strength is calculated according to Equation (1)

$$f_{bm}^{t} = \frac{N_{um}}{\pi d l_v}\left(\frac{0.08}{f_R}\right)^{0.4}, \tag{1}$$

with: f_{bm}^{t} is the average bond strength in the test series; N_{um} – average value of the failure $N_{u(fc)}$ loads in the test series; d – rebar diameter; l_v – embedment length of the rebar in concrete; f_R – relative rib area of the rebars; $N_{u(fc)}$ – failure (peak) load of an individual test converted to concrete class C20/25 or C50/60.

The failure peak load of the test is conventionally set as follows (TR023, 2006): if peak load is reached at a displacement $\delta \le \delta_1$, then use peak load as failure load. If peak load is reached at a displacement load at $\delta > \delta_1$, then use load at δ_1 as failure load.The limit δ_1 is called maximum acceptable displacement and according to TR023 depends on the diameter of the rebar. For rebar diameters smaller than 25 mm, the δ_1 is equal to 1.5 mm

6. Results

In Table 6 the flow table test results of the two mixture mentioned in this paper are given. The spread mixtures on the flow table exhibit a well cohesiveness and no sign of segregation. It can be assert that the flow values of the mixtures assure a well embedment of the rebar into the hole.

Table 6
Consistence Values by Flow Table Method

Mix	Flow *d*, [mm]
1	250
2	270

In Tables 7 and 8 the strength properties of the two mixtures mentioned in this paper are given. Specific gravity is given, too.

Table 7
Average Compressive Strength

Mix	Specific gravity	Compressive strength, [MPa]		
		24 h	7 days	28 days
1	2,230	28.3	53.50	63.50
2	2,250	26.3	47.80	58.50

Table 8
Tensile Strength; Average Values

Mix	Tensile strength by bending, [MPa]			Tensile strength by splitting, [MPa]		
	24h	7 days	28 days	24h	7 days	28 days
1	5.52	8.28	9.18	3.18	4.34	4.72
2	5.32	7.63	8.48	3.05	4.23	4.64

Based on the conversion relationship between the tensile strength by splitting and the axial tensile strength of concrete given by clause (8) of EC2, the calculated axial tensile strength at 28 days is 4.24 MPa for the mortar no.1 and 4,18 MPa for the mortar no. 2. In Table 9 the elasticity modulus and shrinkage strain for the two mixture considered in this study are given.

Table 9
Elasticity Modulus and Dry Shrinkage Strain

Mix	Elasticity modulus, [MPa]		Value of the dry shrinkage after 55days	
	7 day	28 day	mm/m	μm/m
1	36,000	38,000	0.720	720
2	35,000	37,500	0.670	670

In Table 10 the experimental results of the pull-out test for rebars installed with the mixture no. 2 are given. The tests were carried out for a ratio *r* between the hole and the rebar diameter equal to 1.86. In general, in the confined test the bond failure occurs either at the boundary between rebar and mortar (S-M) or at the boundary between the concrete and mortar (B-M) or through failure of the rebar (S).

Table 10
Pull-Out Experimental Results at 7 Days

Characteristics			C35/45	
			Diameter Φ14	
			Embedded $10d_s$	Embedded $7d_s$
Average value of the failure loads, $N_{u(fc)}$	N_{um}		7.94	7.64
Average bond strength of the test	f_{bm}, [MPa]		12.88	17.71
Average bond strength – TR023	f'_{bm}, [MPa]		14.85	20.41
Displacement at the control load	δ_c mm	min.	0.57	0.52
		max	0.70	0.58
Maximum displacement at the failure loads $N_{u(fc)}$	$\delta_{\max}$ mm	min.	1.50	1.50
		max	1.50	1.50
Average yielding force	F_{ym} (tf)		7.94	7.94
Average maximum failure force	$F_{\max,\text{failure}}$ (tf)		9.26	8.88
Failure mode through:			S	S-M

7. Conclusions

A performance Portland fly ash cement-based mortar can provide a good balance between flowability, strength and deformability.

In the fresh stage the mortar exhibit no bleeding or segregation and good flowability. The viscosity of mortar mixture allows introducing of the rebar without difficulties up to the bottom of the hole.

The hardened mortar exhibits high compression strength and satisfactory elasticity modulus. The axial tensile strength is comparable with the C50/60 concrete strength class.

The strain due to the dry shrinkage is comparable with the shrinkage strain of ordinary concrete and much lower than ordinary mortar. The autogenous shrinkage that had developed in the first 24 h was not assessed.

The bond strength values are higher than the aimed values and it can be assert that mortar provides a good anchoring of the steel rebars into the hardened concrete of any class between C12/15 up to C50/60.

According this study and others performed in similar conditions, the maximum bond strength at tests was recorded for an embedment length smaller or equal to 7Φ regardless of concrete class greater than C20/25 (Roşca *et* al., 2014). For greater embedment lengths the bond strength decreases because the failure load is defined conventionally based on the maximum admissible displacement δ_1 *i.e.* when the δ_1 is recorded the conventional pull-out load is equal to the yielding force of the reinforcing steel.

The failure modes recorded at tests are valid for a ratio r between the hole and the rebar diameter greater than 1.86.

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MORTAR DE ACORARE PE BAZĂ DE CIMENT PORTLAND CU CENUŞA VOLANTĂ PENTRU CONECTORI DE OŢEL BETON POSTINSTALAŢI ÎN BETON ÎNTĂRIT

(Rezumat)

Se prezintă un studiu cu privire la performanţele mortarelor pe bază de ciment Portland cu adaos de cenuşă de termocentrală utilizate la ancorarea de bare de oţel beton în beton întărit. Evaluarea performanţelor mortarelor în stare proaspătă se face prin măsurarea consistenţei şi aprecierea coeziunii şi stabilităţii amestecului. Evaluarea performanţelor mortarelor în stare întărită se face prin determinarea caracteristicilor mecanice de rezistenţă şi deformabilitate la termene timpurii şi standard. Efortul unitar de aderenţă ultim este determinat prin încercarea la smulgere. Toate încercările au fost efectuate conform standardelor europene. Rezultatele studiului sunt încurajatoare şi arată că este fezabil să se instaleze bare de armătură de rezistenţă în beton întărit de clasă normală de rezistenţă cu mortar pe bază de liant hidraulic.