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

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Abstract: *This paper presents a study of performance evaluation of fluid cement-based mortars containing limestone 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 7 and 28 days of the fluid mortars used as bonding material. The bond strength of the rebars at 7 days is assessed. The study results were positive showing that it is feasible to anchor resistance steel rebars in concrete of low and medium strength with this mortar.*

Key words: *limestone, cement mortar; anchoring; sand, admixture.*

1. Introduction

A cementitious mortar intended for use in structural anchoring should meet several performance criteria concerning initial properties fluidity, cohesiveness, stability and final properties as strength, stiffness, deformation volume and durability.

Performance properties are made possible by reducing porosity, inhomogeneity and microcracks in the cement mortar and transition zone. This can be achieved using superplasticizers and admixtures materials such as silica fume, fly ash, superfine fly ash, natural puzzolan or even limestone fine granulated. Superior mortar properties obtained in systems in which silica fume is added in combination with superplasticizers is well known. However, the silica fume is an expensive material and quite rare in the Romanian building materials market. There are cheaper alternative materials that can be included in the mixture to achieve a good flowability, cohesiveness and high strength. Mineral admixtures as limestone are cheap and available materials in many countries including Romania.

In plastic stage, the anchoring mortar should be fluid in order to be poured into a hole and to allow easily the insertion of the rebar up to the bottom of the hole. The mixture must be cohesive and resistant to segregation. To satisfy these requirements, the mixture qualitatively must be rich in paste, and from rheological considerations, the yield stress should be quite low and plastic viscosity quite high too.

In the hardened stage, the anchoring mortar must provide high strength, stiffness and low volume deformation. To

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avoid great shrinkage strains the mixture should include as much as possible a small amount of mixing water, a greater amount of aggregate versus a smaller amount of cement, or must to include a low shrinkage admixture. Furthermore, the low water/cement ratio mixture provides in the first 24 hours a great amount of strain due to autogenous shrinkage [3].

2. Objectives

The general objective is to develop performance anchoring materials using ordinary blended cements available into the European market. Particularly in this study the limestone is the involved supplementary cementitious material. The study evaluated the workability and mechanical properties of the proposed cementitious mixes. The bond strength of the reinforcing bars (rebars) is evaluated.

3. Materials and methods

The anchoring mortar is a mixture of Portland-composite cement, aggregate, water and chemical admixture.

The blended cement used in this study is the Portland-composite cement CEM II/A-LL 42,5 which include 6-20% limestone grounded with the Portland clinker at manufacturing.

The aggregate consist of sand, which is divided into two categories coarse and fine sand. The natural river sand, which is considered round and less rough, was used. The maximum size coarse aggregate was 2mm, and in Table 1 the particle size of coarse and fine aggregate is given.

Size of the coarse and fine sand *Table 1*

Fine sand	0,2 – 0,4 mm
	0,4 – 0,63 mm
	0,63 – 0,8 mm
	0,8 – 1,0 mm
Coarse sand	1,0 – 2,0 mm

The used chemical admixture is the polycarboxylate superplasticizer (PCE).

The used methods are concerning to design of the mixture, assessment of fresh properties and hardened properties. Besides, the appropriate method for bond strength was used.

3.1. Design of the mixture

Because of the required properties of the anchoring mortar, see Table 2, which are similar with a concrete of strength class at least C45/55, the used design method of the mixture contains many elements from concrete design method. In fact this mixture can be seen as a micro-concrete mixture.

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

Table 2

Aimed properties of the 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 delivered by Tașca Bicaz cement plant.

Table 3

Properties of the constituent materials

Cement	CEM II/A-LL 42.5	
	Standard Strength	42.5 MPa
	Absolute density	3.0kg/dm^3
Aggregate	Maximum size MSA	2.0 mm
	Bulk loose density	1.43kg/dm^3
	Absolute density	2.65kg/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 [1]. Dreux made an extensive enquiry to collect data about satisfactory concretes. More about Dreux-Gorisse method in [2].

The designing steps of the anchoring mortar mixture are:

- determination of the target compressive strength, see Table 2.
- selection of fresh concrete consistency (fluid).
- selection of the maximum size of aggregate, see Table 2.
- calculate the water/cement ratio using the Bolomey's equation. This equation incorporates the cement strength, plus an adjustable aggregate factor.
- 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 since is limited to a cement dosage of 400 kg/m3. Therefore, a conversion chart, claimed by Cement Concrete Association was used [3]

The chart converts the cement/aggregate ratio into cement dosage based on 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 into 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 for aggregate with specific gravity 2.6 kg/m3 and a cement/aggregate ratio between 2 and 2.5 the minimum cement dosage is 600 kg/m3.

- calculate the (total) 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 2.0mm based on information provided by Dreux [2].
- 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 great 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 cement dosage was considered. Therefore, the required adjustments concerning the workability, see Table 2, were made, the cement dosage was adjusted for a constant water/cement 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	1.75	0.39	0.01
2.	1	2.18	0.36	0.01

3.2. Assess method of 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.

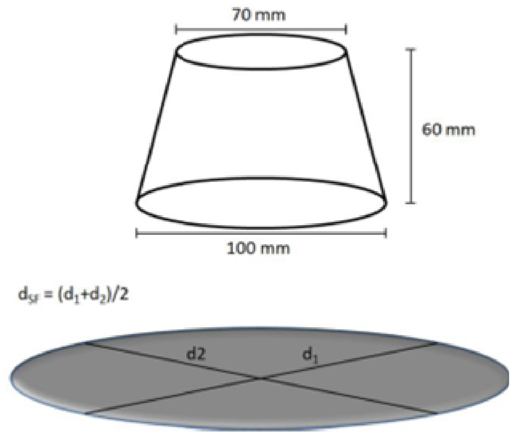

Fig. 1. *The flow table method emphasized by SREN 1015-3*

3.3. Assess methods of the strength properties

The method emphasized by SREN 12190, which is based on the method used by SREN 196-1, was applied to assess the strength of the hardened mortar. The specimen involved into the experimental setup was the 40x40x160mm prism.

Hydraulic testing machines were used to perform the tests. A control force testing machine with maximum capacity of 0.1MN (100KN) and three scale of assessment of the force was used to perform the bending of the specimen. The used maximum force scale was 0.02MN (20KN). The precission on this scale is 10N.

A testing machine manufactured by Technotest, 2006 year of fabrication, with maximum capacity of 3MN was used to compress the specimens. The applied rate of loading was 0.75MPa/sec. The compressive strength of the mortars was measured using steel plates (40x40mm) applied on the end prism. Strength measurements for specimens cured in water were conducted to ages of 3, 7 and 28 days. The results are reported as an average of six specimens.

3.4. Assess methods of the 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 the hardened mortar. The test in compression was performed on mortar prism (40x40x160mm). The secant modulus according to directives given in the foregoing standard was determined.

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 the mortar. The method emphasised by SREN 12617-4 was used to assess the linear dry shrinkage of the hardened mortar. The method involves preparing of mortar prism specimen, curing one day into the mold and afterwards measuring length changes during 55 days using a device of 0,001mm precission, see Fig.2. Length changes of the prism were determined daily.

Fig. 2. *Device to assess the dry shrinkage according to SREN 12617-4*

3.5. Assess method for rebar 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 (EC2). Many tests which are required for usual bonded anchors (ETAG 001, Part5) 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. Also, only tension load can be transferred to cast-in-place rebar connections according to EC2, shear loads on the rebars will not be considered [8].

The tests are done with deformed rebars with properties according to Annex C of EC2 with f_{yk} ≥500 MPa and a related rib area f_R between 0.05 and 0.10 in non-cracked concrete.

The confined test is recommended by TR023 for pulling-out the rebars. In confined tests concrete cone failure is eliminated by the transferring the reaction force close to the anchor into the concrete.

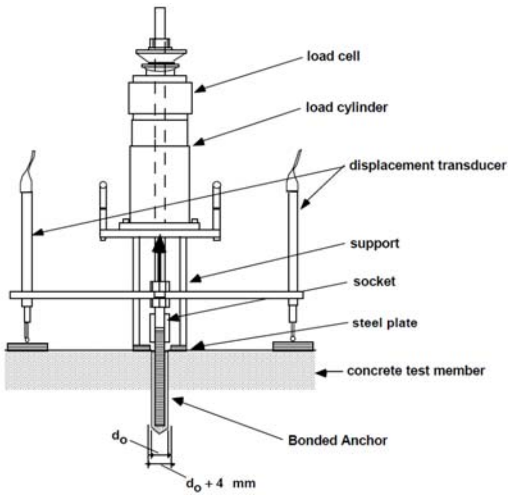

Fig.3. *Example of a tension test rig for confined tests according to [11]*

The developed tension test rig used at tests is given in Fig.4. The concrete specimens consist of block of 300x300x250mm. Diameter bars (Φ14mm) of BST500 steel were embedded within the specimens a length equal to 10Φ and 7Φ.

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 increased progressively in such away that the peak load occured after 1 to 3 minutes from start time [11].

Fig.4. Developed tension test rig for confined tests

4. Assessing of the post-installed rebar

Based on information provided by EOTA TR023, in general it shall be shown by the tests that the post-installed rebar system can develop the same design values of bond resistance with the same safety margin as cast-in-place rebars according to EC2 [8].

In the Table 5 the required bond strength for post-installed rebars in hardened concrete are given. It can be seen that the required bond strength for post-installed rebars is at least forth times greater than the design values provided by EC2 for pre-installed rebars.

Table 5

Concrete strength class	Required bond strength for post-installed rebars according to TR023 MPa
C12/15	7.1
C16/20	8.6
C20/25	10.0
C25/30	11.6
C30/37	13.1
C35/45	14.5
C40/50	15.9
C45/55	17.2
C50/60	18.4

4.1. Determination of the bond strength

According to EOTA TR23 from the results of the tension tests the average bond strength is calculated according to Equation (1)

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

with

$f_{bm}^{t} =$ 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 tested 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 set conventionally as follows:

If peak load is reached at a displacement $\delta \leq \delta_1$, 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 δ1 is called maximum acceptable displacement and according to TR023 depends on the diameter of the rebar, see Table 6.

Values of the δ_1 limit Table 6

d_s (mm)	*δ_1 (mm)*
<25	1.5
25 to 40	2.0
>40	3.0

SREN 1881 impose requirements on the displacement of the loaded end of the rebar at a conventional load, called in this paper control load, for a certain anchorage configuration. SREN 1881 states that the maximum displacement of the loaded end shall be 0.6mm for a Φ16mm rebar embedded 150mm in concrete into a hole of 30mm diameter, which is tensioned by a force equal to 75KN. That means, according to the uniform stress bond model, the bond stress level for 75KN is approximate 9.94MPa. For an equal stress level, correspondent control forces of the others installation configurations can be calculated.

5. Results and discussions

In Table 7 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.

Flow table results Table 7

Mix	Flow d (mm)
1.	270
2.	220

In Table 8, 9, 10 the strength properties of the two mixtures mentioned in this paper are given. Specific gravity is given too.

Average compressive strength Table 8

Mix	Specific gravity	Compressive strength in MPa		
		24h	7 day	28 day
1.	2230	18.5	43.0	52.5
2.	2300	22.5	48.5	57.5

The compressive strength of the hardened mortars fulfils the aimed requirements given in Table 2.

Table 9

Average tensile strength by bending

Mix	Tensile strength by bending in MPa		
	24h	7 day	28 day
1.	4.40	6.90	7.67
2.	4.89	7.80	8.61

Table 10

Average tensile strength by splitting

Mix	Tensile strength by splitting in MPa		
	24h	7 day	28 day
1.	2.47	3.97	4.37
2.	2.78	4.16	4.50

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 is 3.93MPa for the mortar no.1 and 4,05 MPa for mortar no.2.

In Table 11, 12 the deformation properties for the two mixture mentioned in this paper are given.

Table 11

Average value of the elasticity modulus

Mix	Elasticity modulus in MPa	
	7 day	28 day
1.	34000	36000
2.	35500	37000

Table 12

Value of dry shrinkage after 55 days

Mix	Value of the dry shrinkage after 55days	
	mm/m	μm/m
1.	0.820	820
2.	0.740	740

In Table 13 and Table 14 the experimental results of the pull-out test for rebars installed with the mixture no.2 are given. The test are carried out for a ratio r between the hole and the rebar diameter equal to 1,86. In the confined test the bond failure occurs either at the boundary between rebar and the mortar (S-M) or at the boundary between the concrete and mortar (B-M) or through failure of the rebar.

Table 13

Pull-out experimental results at 7 days

Characteristic			C35/45
			Embed $10d_s$
			Diameter
			Φ14
Average value of the failure loads $N_{u(fc)}$	N_{um}		7.81
Average bond strength of the test	f_{bm}		12.67
Average bond strength - TR023	f^t_{bm}		14.61
Displacement at the control load	δ_c mm	min.	0.61
		max	0.85
Max. displacement at the failure loads $N_{u(fc)}$	δ_{max} mm	min.	1.50
		max	1.50
Average yielding force	F_{ym} (tf)		7.85
Average maximum failure force	$F_{max,failure}$ (tf)		9.23
Failure mode through:			Rebar

Table 14

Pull-out experimental results at 7 days

Characteristics			C35/45
			Embed $7d_s$
			Diameter
			Φ14
Average value of the failure loads $N_{u(fc)}$	N_{um}		7.75
Average bond strength of the test	f_{bm}		17.96
Average bond strength - TR023	f^t_{bm}		20.71
Displacement at the control load	δ_c mm	min.	0.31
		max	0.40
Max. displacement at the failure loads $N_{u(fc)}$	δ_{max} mm	min.	1.50
		max	1.50
Average yielding force	F_{ym} (tf)		7.80
Average maximum failure force	$F_{max,failure}$ (tf)		8.98
Failure mode through:			S-M

6. Conclusions

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

The bond strength recorded for an average value of failure load N_{um} according to the TR023, provides a good anchoring of the steel rebars into the hardened concrete of any strength class between C12/15 up to C50/60.

From this study and other study performed by author, 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. For greater embedment lengths the bond strength decreases because the failure load is defined conventionally i.e. is based on the maximum admissible displacement δ_1. When the δ_1 is surpassed, the failure force is equal to the steel yielding force.

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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