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Autor: Karaveziroglou-Weber, Maria / Papayianni, Ioanna
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Long-term Strength of Mortars and Grouts Used in Interventions

Contrôle à long terme de la résistance des mortiers de réparation

Langzeitkontrolle der Festigkeit von Reparaturmörteln

Maria Karaveziroglou-Weber
Assoc. Prof.
Aristotle Univ.
Thessaloniki, Greece

Maria Karaveziroglou-Weber, born in 1948, got her Civil Eng. and Dr. degrees at the Aristotle Univ. of Thessaloniki, Greece, where she now is Assoc. Prof. Since 1979, she is involved in restoration, statical problems and materials for repairing of historical buildings.

Ioanna Papayianni
Assoc. Prof.
Aristotle Univ.
Thessaloniki, Greece

I. Papayianni, born 1949, is Assoc. Prof. at the Civil Eng. Dept of Aristotle Univ. of Thessaloniki. Her research field is on concrete technology and materials for consolidation and restoration of monuments. She specializes in durability and rehabilitation of structures as well as in the development of criteria for suitability of building materials for restoration.

SUMMARY

Measurements are presented of mechanical properties (compressive strength, tensile strength and modulus of elasticity) for a great number of mortar and grout specimens as much as four years old. Lime, natural pozzolana, brick powder, crushed full bricks and sand are the main constituents of these mortars and grouts.

RÉSUMÉ

L'article présente les mesures relatives aux propriétés mécaniques (résistance à la compression, à la traction, module d'élasticité) d'un grand nombre de mortiers et de coulis ayant jusqu'à quatre ans. Les matériaux principaux pour la préparation des mortiers utilisables dans la réparation des bâtiments historiques sont la chaux, le pouzzolane, les fragments de tuiles et de briques, et le sable.

ZUSAMMENFASSUNG

Im vorliegenden Bericht werden die Ergebnisse der im Labor durchgeführten Untersuchungen zur Bestimmung der Druck- und Zugfestigkeit, sowie das Elastizitätsmodul von Reparaturmörteln, die bis zu vier Jahre alt sein können, aufgezeigt. Die für Reparaturzwecke am besten geeigneten Mörtel bestehen hauptsächlich aus Kalk, Puzzolan, Sand und Backstein- oder Ziegelsplitter.

1. INTRODUCTION

Since the mortars and grouts used in repairing old masonries should be compatible to existing ones, "traditional" materials such as lime, natural pozzolana, brick powder and sand prevail among other materials found at market for these mortars' preparation. In addition cement is often added to the mixtures in small quantity in order to fulfill strength requirements. The criteria for the selection of these mortars or grouts are usually based on short time strength tests although pozzolanic reaction to which is mainly due the binding capacity of these mortars follows a slow and time-dependent process.

The aim of this work is to determine the long-time mechanical strength of mortars and grouts. Laboratory tests on 4x4x16 cm specimens according to DIN 18555 were made for the calculation of flexural and compressive strength while the dynamic modulus of elasticity was detrmined by ultrasonic measurements performed on the same specimens.

2. LABORATORY TESTS

The materials used for the preparation of tested mortar and grouts mixtures, as mentioned above, are lime, natural pozzolana from Santorini and Skydra (a place close to Thessaloniki), brick powder, crushed full bricks and river sand as well as cement. The mixing proportions of the mortars prepared in laboratory is given in Table 1 and of the grouts in Table 2.

A great number of specimens were crushed at different ages during a long period (over four years) after mixing to evaluate flexural and compressive strength and modulus of elasticity. The test results for mortars are indicated in Table 3 and for grouts in Tables 4 and 5.

Mortar No	Constituents (by weight)										
	Lime	Santorin earth max size		Skydra earth max size		Portland cement	Sand max size		Crushed bricks max size		Water
		0.1mm	0.25mm	0.25mm	6mm		2mm	6mm	2mm	6mm	
M1	1	1	-	-	-	-	6	-	-	-	2.20
M2	1	-	1	-	-	-	6	-	-	-	2.50
M3	1	-	1	-	-	-	3	-	3	-	2.73
M4	1	-	1	-	-	-	3	-	-	3	2.42
M5	1	-	0.8	-	-	0.2	6	-	-	-	2.17
M6	1	-	-	-	1	-	6	-	-	-	2.25
M7	1	-	-	-	0.8	0.2	6	-	-	-	2.17
M8	1	-	0.8	-	-	0.2	3	-	-	3	2.14
M9	1	-	-	-	0.8	0.2	3	-	-	3	2.08
M10	1	-	-	-	0.2	0.8	3	-	-	3	2.17
M11	1	-	0.2	-	-	0.8	3	-	-	3	2.18
M12	1	-	1	-	-	-	-	6	-	-	1.92
M13	1	-	1	-	-	-	-	6	-	-	1.86
M14	1	-	1	-	-	-	-	5	-	1	1.18
M15	1	-	1	-	-	-	-	3	-	3	1.35
M16	1	-	-	-	1	-	-	6	-	-	1.05
M17	1	-	0.8	-	-	0.2	-	6	-	-	1.10
M18	1	-	0.6	-	-	0.4	-	6	-	-	1.07

Table 1 Mix proportions of mortars

Grout No	Constituents (by weight)							Expanding agent
	Lime	Santorin earth max size <0.25mm	Skydra earth max size <0.25mm	Portland cement	River Sand max size <1mm	Brick powder max size <0.25mm	Water	
G1	1	0.8	–	0.2	1	1	1.869	–
G2	1	–	0.8	0.2	1	1	1.875	–
G3	1	–	0.6	0.4	1	1	1.875	–
G4	1	–	0.6	0.4	2	–	1.530	–
G5	1	0.6	-	0.4	-	2	2.187	–
G6	1	2	–	0.4	–	-	1.720	0.034
G7	1	2	–	0.4	–	–	1.788	-
G8	1	2	–	0.8	3.8	–	2.250	0.038
G9	1	0.8	–	0.2.	1	1	1.670	0.020
G10	1	–	0.8	0.2	1	1	1.610	0.020

Table 2 Mix proportions of grouts (by weight)

Age	28 days			1 year			5 years		
Mortar No	Strength		Modulus of Elasticity	Strength		Modulus of Elasticity	Strength		Modulus of Elasticity
	Tensile N/mm^2	Compressive N/mm^2	N/mm^2	Tensile N/mm^2	Compressive N/mm^2	N/mm^2	Tensile N/mm^2	Compressive N/mm^2	N/mm^2
M1	0.32	0.54	1709	0.28	0.87	1756	0.39	0.83	1827
M2	0.23	0.34	1594	0.29	0.74	1643	0.28	0.71	1545
M3	0.25	0.84	1340	0.24	0.97	1375	0.22	0.77	1106
M4	0.26	1.32	1807	0.32	1.46	1936	0.23	0.81	1290
M5	0.31	1.44	2431	0.21	0.61	2677	0.21	0.62	1330
M6	0.22	0.54	1271	0.32	1.55	2487	0.36	1.16	2419
M7	0.30	0.52	2103	0.36	0.88	2096	0.36	0.95	2263
M8	0.52	2.60	3038	0.53	2.03	2819	0.54	1.89	2421
M9	0.71	3.07	3462	0.56	2.26	3473	0.52	2.00	2420
M10	1.58	6.26	6812	1.25	5.69	6465	1.25	4.48	5138
M11	2.01	6.84	6740	1.35	6.73	6713	1.76	5.95	5715
M12	0.24	0.70	1505	0.22	0.93	2018	0.28	0.83	1919
M13	0.26	0.93	2390	0.27	1.08	2235	0.32	0.83	2069
M14	0.27	1.25	2446	0.30	1.42	1241	0.24	1.10	2348
M15	0.20	0.78	1802	0.29	1.12	2297	0.32	1.04	2437
M16	0.14	0.65	1640	0.23	1.26	1996	0.20	1.10	1900
M17	0.24	1.27	2774	0.42	1.79	3754	0.42	1.77	3221
M18	0.48	1.76	4184	0.56	2.57	5045	0.74	2.68	4616

Table 3 Mortar strength and modulus of elasticity

Age	7 days		14 days		21 days		28 days		90 days		1540 days	
Strength	Tensile	Compressive	Tensile	Compressive	Tensile	Compressive	Tensile	Compressive	Tensile	Compressive	Tensile	Compressive
Grout No	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2
G1	0.10	0.21	0.11	0.34	0.16	0.64	0.22	0.72	-	0.80	0.56	1.01
G2	0.12	0.25	0.10	0.35	0.20	0.42	0.26	0.61	-	-	0.43	1.25
G3	0.20	0.44	0.37	0.75	0.45	0.98	0.66	1.55	0.71	2.00	0.82	2.46
G4	0.12	0.38	0.39	0.67	0.37	0.81	0.34	1.18	0.49	1.60	1.06	2.75
G5	0.34	0.42	0.45	0.97	0.64	1.91	0.50	2.65	0.62	2.62	1.20	2.62
G6	0.07	0.28	0.20	0.53	0.40	0.90	0.42	1.30	0.67	1.47	1.04	1.62
G7	0.09	0.32	0.23	0.52	0.44	1.00	0.53	1.44	0.64	1.53	0.98	2.16
G8	0.43	1.13	0.75	2.14	1.13	3.46	1.16	2.96	1.43	3.47	1.64	3.63
G9	0.04	0.20	0.25	0.44	0.48	1.06	0.44	1.39	0.39	1.32	0.87	1.58
G10	0.05	0.24	0.29	0.49	0.37	0.88	0.39	1.20	-	0.98	0.66	1.31

Table 4 Strength of grouts at different ages

Dynamic modulus of elastisity [N/mm^2]						
Age / Grout No	7 days	14 days	21 days	28 days	90 days	1540 days
G1	527	1015	1266	1461	1547	1675
G2	508	1050	1456	1541	1616	1572
G3	1766	–	1942	2544	2548	2549
G4	1392	2013	2248	2325	2761	2939
G5	1210	1729	2242	3400	3456	2537
G6	960	1049	1832	1801	1731	1743
G7	–	1310	1918	2071	2182	1922
G8	3930	4390	5088	4852	5082	5066
G9	787	1533	2216	-	2262	2130
G10	670	1238	1847	1873	1857	1993

Table 5 Dynamic modulus of elasticity of grouts

3. DISCUSSION

3.1 Mortars

Regarding the test results of Table 3 and the mortar composition given in Table 1 it can be said in general that the addition of ceramic material as well as of cement increases the strength of the mortars. The aggregate gradation influences also the mechanical properties (mortar M12 has a different aggregate gradation than mortar M13 mentioned in Table 1). These remarks were commended in a previous work of the authors [1].

In relation to the strength development with time it can be said the following: Mortars without ceramic material or cement (M1, M2, M6, M12, M13, M16) show a slight increase in flexural strength from 28 days up to 1 year. After this age the strength remains almost unchanged except for the one of mortar M6 and M16 which are made with pozzolana from Skydra and showed a decrease at five years. The development of the flexural strength increases up to 60% from 28 days to 1 year. The compressive strength of mortars M1, M2, M6, M12, M13, M16 increases with the time and after one year decreases slightly. The dynamic modulus of elasticity follows almost the same process as the compressive strength, but its values vary strongly.

Mortars M3, M4, M14, M15 with ceramic material show an increase of strength and modulus of elasticity till one year and after this point a light decrease. These results are in agreement with those found by other researchers [2] in relation to modern mortars.

Mortars M5, M7, M8, M9, M17 in which 20% of natural pozzolana has been replaced by cement do not show significant variations in flexural strength after 28 days. Mortar M18 has almost the same strength as mortar M8, although the amount of cement is double (40% of natural pozzolana has been replaced by cement). This may be owing to the latent hydraulic activity of ceramic material. Mortars M10 and M11 with 80% cement and 20% pozzolana show a decrease of strength and modulus of elasticity after 28 days.

3.2 Grouts

Cement and ceramic material seem to have the same influence on mechanical properties of grouts as in the case of mortars. Strength measurements of grouts

were made from 7 days up to 4 years. Grouts with 20% cement and 80% pozzolana (G1,G2,G9,G10) and the ones with 40% cement and 60% pozzolana (G3, G4, G5, G6, G7) show generally an increase in strength with time (Table 2, Table 4, Table 5). The strength development of these grouts is shown in Fig.1. The same behaviour presents G8 with 80% cement and 20% pozzolana.

The increase of grout strength with time has also been observed in previous works done at the Laboratory of Reinforced Concrete [3,4].

4. CONCLUSIONS

The long-time strength of mortars and grouts must be taken into account in the analysis of bearing capacity of under restoration masonry as well as the masonry deformations. Therefore, a slight decrease in mortar strength must be expected after one year. In contrast, grout strength is slightly increased after years. This leads to the suggestion that in order to achieve the require strength for repairing a masonry a higher strength mixture should be designed.

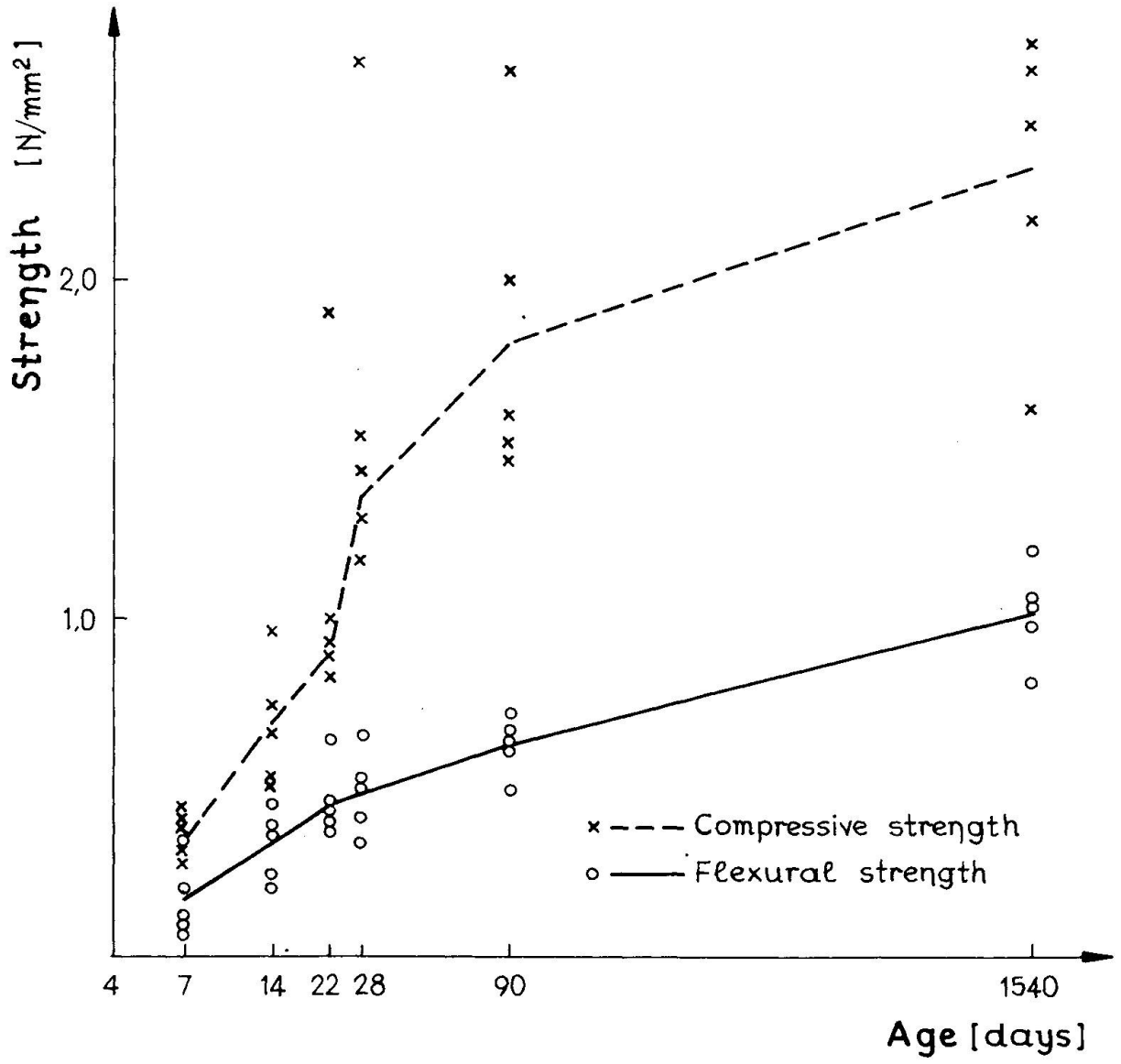

Fig. 1 Strength development of grouts G_3, G_4, G_5, G_6, G_7

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