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Effect of Ground Water on the Mechanical Properties of Micro Cement Mortar

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Abstract: *The main aim of this research is to investigate the mechanical properties of micro cement mortar to be used to produce micro reinforced concrete/ ferrocement elements when exposed to the ground water and compare the measured values with bare specimens when exposed to tap water under the same conditions of temperature and relative humidity.The first objective of the present work was to assess durability of micro cement mortar by casting two groups of specimens. The first group was cured under ordinary tap water, and the second group was submerged in a water contains sulphates, magnesium, sodium, and calcium at concentrations similar to those that exists in underground water. Besides, the durability performance of micro cement mortar was investigated under severe exposure conditions. Compressive strength, splitting tensile strength, flexural strength, and flexural toughness of reinforced micro cement mortar were investigated for both types of specimens at various ages of exposure. Results showed that under the action of aggressive solution, micro cement mortar have high durability, and high resistance to sever exposure conditions.*

I. Introduction

One of the principal problems of concrete durability is the external attack of sulfate, chloride, magnesium, sodium and calcium salts present in soil and underground water. Impact resistance of micro reinforced concrete slab is presented by Al-Rifaie and Ahmed[1]. The impact resistance was defined as a number of blows required to cause perforation of the slabs. A total of 24 simply supported square slab specimens 500x500 mm were cast and tested under impact loads varying the number of wire mesh layers and slab thickness. The measured values show that micro reinforced concrete is very adequate to resist the impact, due to its higher ability of absorbing impact energy and the damage is localized at the impact zone and no spalling of large mortar fragments occurs.

Al-Rifaie et al[2], present research examined the compressive and flexural strength of Nano cement mortar by using micro cement, micro sand, Nano silica and Nano clay in developing Nano cement mortar which can lead to improvements in Ferrocement construction. The measured results demonstrate the increase in compressive and flexural strength of mortars at early stages of hardening. In addition, the influence of heating on compressive strength of cement mortar was carried out. General expressions to predict the compressive strength, modulus of rupture for the developed nano cement mortar in were proposed.

Al-Rifaie et al[3], carried out a research to examine the compressive and tension strength of nano cement mortar by using micro cement, micro sand, nano silica and nano clay which can lead to improvements in concrete construction. The results have shown an increase in both the compressive and tensile strength of mortar at early stages of hardening. For testing purpose, 50 mm cubes and 250×50×10 mm prisms were cast and tested for determining the compressive and tensile strength of nano-cement mortar. The parameters that were taken into consideration during the investigation were micro sand, micro cement, nano silica, developed nano clay and naphthalene sulphonate as super- plasticizers. It was concluded that the measured values demonstrate a significant increase in the tensile strength of the developed mortar. Accordingly, an empirical equation was formulated for the tensile strength prediction.

The effect of nano clay on the mechanical properties and microstructure of Portland cement mortar was investigated by Morsy et al[4]. The blended cement used consists of ordinary Portland cement and nano-metakaolin. The blended cement mortar was prepared using cement –sand ratio of 1:2 by weight with water-binder ratio as 0.5. The measured values showed that the compressive and tensile strengths of the cement mortars with nano metakolin were higher than plain cement mortar with the same water – binder ratio. The enhancement in tensile strength was 49%, whereas the enhancement in compressive was 7% at 8% metakolin.

A study concerning the production of self-flowing castable cement-based building elements incorporating high amounts of quarry dust was investigated in laboratory scale by Galetakis et al[5].. Quarry dust, micro cement, water, and concrete admixtures were mixed and casted in steel molds for the production of the specimens. The initial study of mixtures composition was based on the Andreassen particle packing model, while the final mix design was determined via Box–Behnken fractional factorial design of experiments, in combination with the response surface method. The compressive strength and water absorption values of hardened specimens exceed

the relevant technical requirements currently in force, regarding load-bearing as well as decorative building elements, thus opening a new promising field for the utilization of this by-product. They had concluded that the main factor that affects the uniaxial compressive strength with 28 days and water absorption of the prepared specimen is the cement-to-filler ratio. Microsilica-to-cement seems to play an important role in water absorption values. The interactions of cement-to-filler and microsilica-to-cement and filler were also proven important.
The effects of various micro and nano cementitious materials on the long-term durability of mortars against external sulfate attack were studied by Atahan and Arslan[6]. For this purpose, nano (colloidal) silica, micro silica, fly ash and ground granulated blast-furnace slag were selected with various replacement ratios. All the samples were kept in 5% sodium sulfate solution for approximately 3 years and the expansions caused by sulfate attack were monitored. Additionally, at the end of 3 years of exposure, residual flexural strength, compression strength and ultrasonic pulse velocity of mortars were determined and their results were compared with the reference samples which do not contain mineral additives and cured in water. Results have shown that significant improvement against sulfate attack was achieved by using the above additives by properly selecting its dosage.

II. Experiment

The experimentalprogram for each of the three ratios of the micro cement mortar considered in the present work is detailed in Table (1). The following is the materials used in preparing the testing specimens.

1. Materials

The cement used in all mixes of the present investigation was an ordinaryPortland cement (ASTM type I).
Natural sand was used as a fine aggregate. The grading of sand, as tabulated in Table (2), is confined to the requirement of ASTM-C33-86and the B.S: 1973 grading requirements.
Ordinary tap water was used for mixing and 28 curing days for all specimens.
The results of underground water analysis prepared by the National Center for Geological Survey and Mining is giving in Table (3)[7].
The salts used in preparing the solution are given in Table (4). Potable water was used as a solvent for these salts. Tables (5) and (6) give type and concentration of ions and cations. Then, water contains chlorides, sulphates, magnesium, sodium, and calcium at concentrations similar to those that exists in underground water was prepared.

Mild steel galvanized woven wire meshes of hexagonal typewere used throughout the present investigation. The average diameter was 0.7 mm. Several strands of wireswere taken from the mesh, straightened and tested under tension to determine the yield stress (f_y), ultimate stress ($f_{ult.}$) and modulus of elasticity (E_s). Table (7) gives the average values of the results obtained. A chemical test was carried out on a sample taken from the wiremesh to determine the chemical properties. The test results indicated that thewire mesh is steel with some percentages of metallic materials as given in Table(8).

2. Preparation of Salts Solution

One of the principal problems of concrete durability is the external attackof sulfate, chloride, magnesium, sodium and calcium salts, especially thosepresent in soil and underground water in the southern parts of Iraq. The results of underground water analysis are prepared by the National Center for Geological Survey and Mining[7].

3. Mould Preparation

Three types of Steel moulds were used in this work. Cubic moulds 100 mm were used for compression test, cylindrical moulds 100x300 mm were used for indirect tension test and prismaticmoulds 100x100x400 mm used for flexural and deflection tests.

4. Mix Design and Procedure

As it was stated earlier, three mixes were considered in the present investigation (c:s ratio of 1:1, 1:1½, and 1:2). The water: cement ratio for all mixes was 0.4. The mixing of mortar was carried out in a tilting pan type mixer of 0.08 m^3capacity. In all mixes of mortar, the sand and cement were first mixed dry for 60 seconds, then water was added for a further 120 second.After mixing, the mortar was poured in lightly oiled steel moulds in layers of50 mm depth and well compacted by a table vibrator for about 20 seconds, for each layer to give an adequate compaction. The specimens were then covered by nylon and left undisturbed until the moulds were stripped after (24±1) hours from the time of adding the water to the mixture.In all tests, the specimens were cured under ordinary tap water for 28 days. After the curing stage, the specimens were divided into two groups. The first group was kept in tap water until testing, and the other group was transferred to remain under the effects of the prepared ground water until testing. Testing ages considered were 30, 60 and 90 days.

III. Testing of Specimens

1. Compressive strength tests

For compressive strength test 54 (100 mm cubic) specimens were cast and tested by using a standard testing machine with a capacity of 2000 kN. The loading was applied at a rate of 15 MPa per minute. The average of three specimens was considered for each testing age and the compressive strengthf_{cu} is given by (P/A), whereP(N) is the maximum applied load and A is the surface area (100x100 mm^2). The tests were carried out according to B.S: 1881: part 116.

2. Testing of splitting tensile

54 cylinder specimens (100x200 mm) were cast and tested for splinting tensile accordance with ASTM C496-86. Tests were performed by using a standard testing machineat a rate of 1.5 MPa per minute. The average of the three cylinders was considered for each test. The splitting tensile strength is given by the following equation:

$$ft = \frac{2P}{\pi(d)(l)}$$

In which,
$ft = spliting\ tensile\ strength, MPa.$
$P = maximum\ applied\ load, N.$
$d = diameter\ of\ cylinder, mm.$
$l = length\ of\ cylinder, mm.$

3. Testing of modulus of rapture

The flexural strength known as themodulus of rupture is carried outon cement mortar and the concept is basedon the elastic beam theory. 54 prismatic specimens were cast with dimensions (100x100x400 mm). The specimens were tested in accordance with B.S: I88 I: part 118, by using flexural strength test machine of 300 kN capacity. The fracture occurs within the central one-third of the prism for all specimens; therefore the modulus of rupture was calculated using the following formula:

$$fr = \frac{Pl}{bd^{2}}$$

In which,
$fr = modulus\ of\ rupture, MPa.$
$P = maximum\ applied\ load, N.$
$l = effective\ span, mm.$
$d = depth\ of\ specimen, mm.$

4. Testing of Flexural toughness (deflection):

For deflection test,6prism specimens (100x100x400 mm), reinforced with 6-layers of wire mesh,were cast and tested according to ASTM C 10 18-89." The prisms(three typeof mixing ratio used) were tested using a third-point loading over a simply supported span of 300 mm. The testing was done using WALPERT type machine and the loadwas applied, then deflection was measured by means of dial gaugewith least count of 0.01. The load wasapplied at specified rate so that the defection of the specimen at mid-span increases at a constant rate within the range of 0.05-0.10 mm/min.The specimens were tested up to the period of 90 curingdays. The average of three prisms was taken at each test.

IV. Results

1. Compressive strength:

The measured values of the tested specimens exposed to ground water were compared to the values of tested specimens exposed to tap water as given in Table (9). In general, the compressive strength of all kinds of mixing increases whenever the length of time of the test age of the specimens whichwere cured under ordinary tap water is increased.Whereas specimens that were exposed to ground water exhibitedan increase in the compressive strength in the early age compared with the firstone. As for later ages, the specimens showed an appreciable reduction in strengthwith an increase in the curing age. This behavior is ascribed to the leaching limecompounds which, in turn, leads to an increase in porosity and reduction instrength.

2. Splitting tensile strength:

In general, the splitting tensile strength of all kinds of mixing increases whenever the length of time of the test age of the specimenswhich were cured under ordinary tap water is increased.Whereas specimens that were exposed to ground water effect exhibitedan increase in the splitting tensile strength in the early age compared with thefirst one. As for later ages, the specimens showed an appreciable reduction instrength with an increase in the curing age. This behavior is ascribed to the leaching lime compounds which in turn, leads to an increase in porosity andreduction in strength. The measured values are given in Table (10). Results demonstrated that, in general, all specimens exhibited a continuous increase in splitting tensile strength with anincrease in the testing age when theyare under the effect of tap water.

3. Flexural strength (modular of rapture) of micro cement mortar:
The effect of curing days on the flexural strength of various mixingratio of micro cement ratio is given in Table (11).

4. Flexural tests on micro reinforced concrete specimens
The results of the deflection test at 90 curing daysare shown in Figures (1) to (3).

V. Conclusions

The results indicated that with the progress of the testing age of the cement mortar specimens, the flexural strengths are increased in both types of curingwhether with ordinary tap water or with underground water. The measured results have shown that by increasing the amount of cement in micro cement mortar tend to decrease the measured deflection whether the micro reinforced cement mortar cured under tap water or underground water.

Underground water affects micro reinforced cement mortar as in the early age of testing. It may be seen that strength increases in all tests because of soluble salts are combined with hydrated cement compounds and this will lead to the formation of gel compounds which are responsible for resistance. At later age, a noticeable reduction in resistance taken place in most tests which is due to the leaching of lime compounds which leads to an increase in porosity and reduction in strength.

Table (1): Experimental program for each cement: sand ratio

Type of test	Specimens/ No.	Ordinary tap water	Simulation of ground water (sulphates, chlorides, magnesium, sodium, and calcium)
Compressive strength test of micro cement mortar.	Cube (100 mm)/ 18	9 cubes, average values of 3 cubes for each of the curing ages (30, 60, 90 days).	9 cubes, average values of 3 cubes for each of the curing ages (30, 60, 90 days).
Indirect test of micro cement mortar.	Cylinder (100x200 mm)/ 18	9 cylinder, average values of 3 cylinder for each of curing ages (30, 60, 90 days).	9 cylinder, average values of 3 cubes for each of curing ages (30, 60, 90 days).
Flexural test of micro cement mortar.	Prisms (100x100x400 mm)/ 18	9 prisms, average measured values of 3 prisms for each of curing ages (30, 60, 90 days).	9 prisms, average values of 3 prisms for each of curing ages (30, 60, 90 days).
Toughness test for cement mortar reinforced by 6-layers of wire mesh.	Prisms (100x100x400 mm)/ 18	3 prisms, average measured values with curing ages of 90 days.	3 prisms, average measured values with curing ages of 90 days.

Table (2): Grading of sand used in the present investigation.

Sieve size mm	Passing %	
	Sand	Limiting ASTM-C33-86 BS 882: 73
4.75	100.0	90-100
2.36	100.0	85-100
1.18	85.6	75-100
0.60	69.2	60-79
0.30	34.5	12-40
0.15	7.3	0-10

Table (3): Concentration of Ions in ground water.

Type of Ions	Concentration
Chloride	20,000-40,000 ppm
Sulphate	5,000-7,000 ppm
Magnesium	1,500-2,000 ppm
Sodium	10,000-20,000 ppm
Calcium	1,000-1,500 ppm

ppm: mg/ L of water.

Table (4): Type and concentration of salt used in the present investigation.

Type of salt	Concentration ppm/ gm/L	% by wt. of water
NaCL	45100.4/ 45.1	4.51
CaCL2. $2H_2O$	5512.5/ 5.5	0.55
$MgSO_4$. $7H_2O$	17967.7/ 17.967	1.79

Table (5): Type of Ion and its concentration.

Type of Ion	Concentration ppm
CL	30019.5
SO_4	7002.7

Table (6): Type of cation and its concentration.

Type of cation	Concentration ppm
Mg	1773
Na	17750
Ca	1500

Table (7): Mechanical properties of wire mesh used in the present work.

Wire mesh, 0.7 mm diameter	
Yield strength (f_y), MPa*	300
Standard deviation	8.2
Ultimate strength (f_u), MPa	520
Standard deviation	18.6
Modulus of elasticity (E_s), MPa	67000
Standard deviation	126

*The yield strength was selected as the stress corresponding to a total strain of 0.0050 (ASTM standards A82 and A18).

Table (8): Chemical properties of wire mesh used in the present work.

Cr %	Cu %	Mn %	Ni %	C %	S %	Si %
0.0090	0.0450	0.3850	0.0360	0.0536	0.0187	0.0098

Table (9): The measured values of compressive strength, MPa.

Type of curing water	Mixing ratio 1:1			Mixing ratio 1:1½			Mixing ratio 1:2		
	Testing value			Testing value			Testing value		
	30 days	60 days	90 days	30 days	60 days	90 days	30 days	60 days	90 days
Tap water	49.76	53.45	56.32	45.20	48.05	50.61	43.55	47.40	50.70
Ground water	54.70	56.25	55.83	46.30	46.66	45.87	42.32	41.95	41.05

Table (10): The measured values of splitting tensile strength, MPa.

Type of curing water	Mixing ratio 1:1			Mixing ratio 1:1½			Mixing ratio 1:2		
	Testing value			Testing value			Testing value		
	30 days	60 days	90 days	30 days	60 days	90 days	30 days	60 days	90 days
Tap water	4.35	4.49	4.66	4.03	4.29	4.34	3.29	3.42	3.61
Ground water	4.53	4.55	4.49	4.26	4.28	4.23	3.22	3.27	3.24

Table (11): Flexural strength of micro cement mortar developed in present work, MPa.

Type of curing water	Mixing ratio 1:1			Mixing ratio 1:1½			Mixing ratio 1:2		
	Testing value			Testing value			Testing value		
	30 days	60 days	90 days	30 days	60 days	90 days	30 days	60 days	90 days
Tap water	8.18	8.7	9.30	7.83	8.05	8.37	7.56	7.85	8.04
Ground water	8.4	8.53	8.66	7.95	8.07	8.15	7.45	7.55	7.58

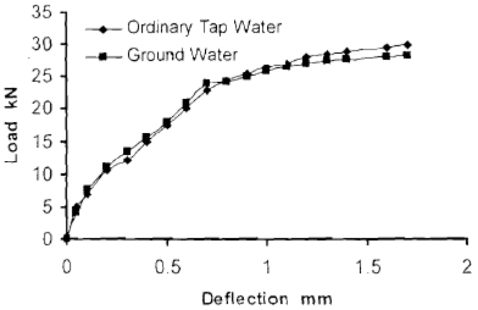

Figure (1): Load - Deflection relationship for mixing ratio 1:1 attesting age 90 days.

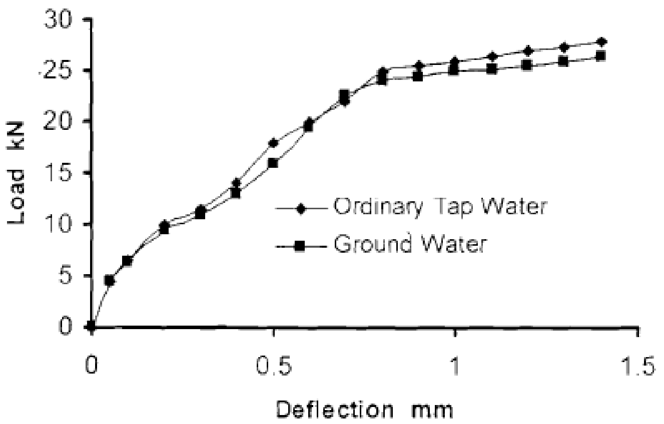

Figure (2): Load - Deflection relationship for mixing ratio 1:1½at testing age 90 days.

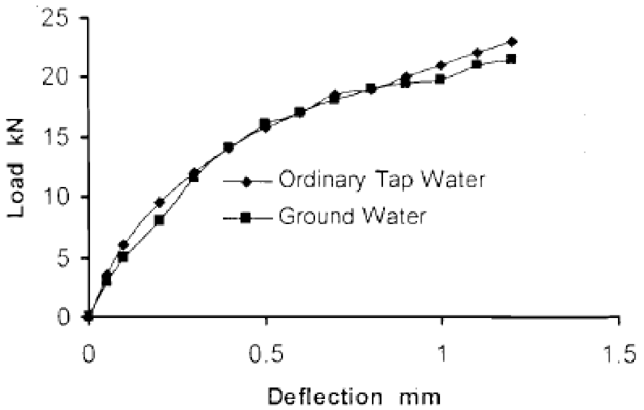

Figure (3): Load - Deflection relationship for mixing ratio 1:2 at testing age 90 days.

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