



# UNITED NATIONS

## ECONOMIC AND SOCIAL COUNCIL

Distr.  
LIMITED  
E/ESCWA/HS/87/WG.1/WP.15  
26 October 1987  
ORIGINAL: ENGLISH

### ECONOMIC AND SOCIAL COMMISSION FOR WESTERN ASIA

Expert Group Meeting on Energy-Efficient  
Building Materials for Low-cost Housing  
14-19 November 1987  
Amman - Jordan

#### PROPERTIES OF CONCRETE MIXED WITH SEA WATER

UN ECONOMIC AND SOCIAL COMMISSION  
FOR WESTERN ASIA

NOV 17 1987

PROPERTY - DOCUMENT SECTION

Asim YEGINOBALI\*  
JORDAN

\* Not an official paper. The views expressed are those of the author(s) and do not necessarily reflect any views or positions of the United Nations.



## 1. INTRODUCTION

Whenever energy-efficient materials for low-cost concrete housing are considered the attention is usually focused on the cements and aggregates and how to economize on them. However, there can be instances where the mixing water, the other concrete ingredient, may also require consideration. Transporting suitable water over long distances due to its local scarcity or need for treatment and desalination processes can be mentioned as examples.

Water used for mixing concrete should not result in harmful chemical reactions with the cement, aggregate, reinforcing steel and should not accelerate the deterioration of concrete. Considering the complexity of such reactions "drinkable" water is usually recommended for this purpose. On the other hand, water of such quality may not be available even for drinking in many regions of the developing world. In such cases either whatever water available is used for mixing concrete or one of the costly solutions mentioned above are tried to secure water of suitable quality. The decision can not be justified unless the effects of the available and supposedly unsuitable mixing waters on important concrete properties are determined using the local materials.

Considerable research has been done to identify the chemicals in mixing water that can be harmful to concrete and to determine their tolerable limits. Sea waters or waters with similar composition were usually included in these studies. A survey of the literature indicated disagreements among the findings of various investigators on the effects of such waters on certain concrete properties. For instance, in an early study using a sea water with 35 g/l salinity, Abrams reported some decrease in compressive strength after 7 days [1]. According to another study even with much higher salinities increased 28 day strengths could be obtained

[2]. Concerning the effects of sea water mixing on the steel reinforcement there were conflicting opinions [3, 4]. Effects on setting times and durability were also subjects of discussion.

Building codes and specifications usually contain some clauses on the quality of the mixing water for concrete and directly or indirectly comment on the use of sea water for this purpose. Some bring specific limitations on the composition of the water such as allowable salinity and sulfate contents and/or state permissible reductions in strength. Others permit the use of any water encountered in nature providing that it will not cause adverse effects in concrete and in reinforcing steel. Both approaches may simultaneously exist in the standards and specifications of a country [5, 6].

Considering the somewhat conflicting results from the previous studies and the different approaches by the specifications, it was felt worthwhile to conduct a comprehensive experimental study involving the local cements and sea waters in Turkey. Turkey has a long coast line and is surrounded by sea waters of varying composition which occasionally have been used in mixing concrete. Similarly, many arid regions of the developing countries in the Middle East and North Africa are situated close to sea and using sea water for mixing concrete may have to be considered. Therefore, it is hoped that the findings of this study which was conducted at the Middle East Technical University in Ankara, will be of general interest for the region.

## 2. MATERIALS AND EXPERIMENTAL PROGRAM

The experimental program involved the use of three different sea waters for preparing the paste, mortar and concrete specimens and a tap water for mixing the control specimens. Four different portland cements were considered and the type and grading of aggregate were kept constant.

Sea waters were obtained from western Black Sea, southern Marmara and eastern Mediterranean shores of Turkey. The locations were chosen to obtain a wide range of salinity. The compositions of sea waters used in the experiments are shown in Table 1. (The composition of Red Sea which may be more typical for the region is also included for comparison purpose).

Table 1. Composition of the Sea Waters

Principal ions (g/l)	Black Sea	Marmara Sea	Mediterranean Sea	Red Sea
Na	4.90	8.10	12.40	12.20
K	0.23	0.34	0.50	0.44
Mg	0.64	1.04	1.50	1.88
Ca	0.24	0.33	0.37	0.51
Cl	9.50	14.39	21.27	22.70
SO <sub>4</sub>	1.36	2.03	2.60	3.16
HCO <sub>3</sub>	0.22	0.18	0.16	0.15
Total	17.09	26.41	38.80	41.04
pH	7.4	7.9	8.0	8.2

The tap water was the water used at the campus of the university with the following composition: Cl: 70 mg/l, SO<sub>4</sub>: 14 mg/l, pH: 7.0.

The four different portland cements were selected among the commonly produced types in Turkey. Together with an ordinary portland cement, slag cement with 30% blast furnace slag addition, trass cement with 20% trass

addition and admixed cement with 10% trass addition were used in the experiments. Their properties are shown in Table 2.

Table 2. Properties of the Cements

Chemical %	Ordinary	Slag	Trass	Admix
SiO <sub>2</sub>	20.5	23.8	24.6	23.8
Al <sub>2</sub> O <sub>3</sub>	7.0	8.4	6.4	7.3
Fe <sub>2</sub> O <sub>3</sub>	2.6	2.4	2.8	3.2
CaO	51.8	48.0	45.1	50.8
MgO	3.9	4.8	1.6	1.6
SO <sub>3</sub>	3.3	2.8	2.1	2.2
Ignition loss	4.0	3.5	4.9	4.7
Insoluble	0.9	0.8	19.5	9.1
Physical				
Specific gravity	3.10	2.96	2.89	3.03
Specific Surface (m <sup>2</sup> /kg)	362	325	369	344
Normal consistency (%)	28	27	30	28
Initial set (hr: min)	2:55	3:10	3:05	4:40
Final set (hr: min)	5:10	5:10	8:10	6:55
Le Chatelier (mm)	2	3	3	4
Strengths (kgf/cm <sup>2</sup> )				
7-day flexural	56	49	50	45
28-day flexural	72	73	63	68
7-day compressive	237	213	210	213
28 day compressive	374	350	299	334

The aggregate for the concrete mixes was natural sand and gravel with maximum particle size of 30 mm. It was combined from four different size groups to provide uniform and proper grading. For most of the mortar mixes standard sand was used to minimize variations in aggregate properties.

The experimental program involved the tests on different properties of pastes, mortars and concretes mixed with the sea waters and comparing the results with those obtained by using the tap water. The tests and investigated properties were as follows:

Cement pastes: normal consistency, soundness, setting times heat of hydration, porosity.

Mortars: consistency, flexural strength, compressive strength, sulfate resistance, reinforcing steel corrosion.

Concretes: air content, workability, compressive strength, splitting tensile strength, reinforcing steel corrosion.

Tests were performed according to Turkish standards wherever applicable, which were mostly similar to the standard procedures in U.S.A. or in Germany. At least three repetitions or three test specimens were used for each property tested to obtain the final average value. Full combination of the mixing water-cement variables resulted in 16 mixes which were prepared and tested for most of the properties.

For brevity, different mixes were designated as follows:

#### NOTATION

To: Tap with ordinary, Bo: Black sea with ordinary, Mo: Marmara with ordinary, Meo: Mediterranean with ordinary.

Ts: Tap with slag, Bs: Black sea with slag, Ms: Marmara with slag, Mes: Mediterranean with slag.

Tt: Tap with trass, Bt: Black sea with trass, Mt: Marmara with trass, Met: Mediterranean with trass.

Ta: Tap with admixed, Ba: Black sea with admixed, Ma: Marmara with admixed, Mea: Mediterranean with admixed.

### 3. PROCEDURES AND RESULTS OF EXPERIMENTS

#### 3.1 Experiments with Cement Pastes

The normal consistency of the paste mixes was determined by using the Vicat instrument. Percentages of water to bring the pastes to normal consistency varied between 27-30 according to the type of cement. Mixing with sea waters did not affect this property significantly.

The soundness of the pastes was determined by measuring the total opening between the needles of the Le Chatelier molds after accelerated curing. The results ranged between 1-4 mm for different mixes, sea waters causing slight or no effect.

Initial and final setting times for the pastes were determined by the Vicat instrument. The results are shown in Table 3.

Table 3. Setting Times, Heat of hydration and Porosity of Pastes

Mix	Setting times (hr:min)		Heat of hydration (cal/g)		Porosity (%)
	initial	final	7 day	28 day	
To	2:55	5:10	68	76	29
Bo	2:45	4:50	70	76	-
Mo	2:30	4:45	70	76	-
Meo	2:20	4:35	73	76	27
Ts	3:10	5:10	64	71	30
Bs	2:55	4:55	63	71	-
Ms	2:50	4:50	67	68	-
Mes	2:40	4:40	68	73	28
Tt	3:05	8:00	64	68	-
Bt	2:45	7:45	64	68	-
Mt	2:35	7:30	66	68	-
Met	2:25	7:10	64	69	-
Ta	4:40	6:55	60	67	-
Ba	4:30	6:45	68	70	-
Ma	4:20	6:50	65	69	-
Mea	4:05	6:35	62	70	-



Heat of hydration evolved from the pastes at the end of 7 and 28 days was determined by using a calorimeter and Beckmann thermometer. The results are given in Table 3.

The effect of sea water mixing on the porosity of hardened cement pastes were investigated by determining the absorption capacity on 5 x 10 cm cylindrical specimens after 60 days of moist curing. Only four different mixes were used. The results are included in Table 3.

### 3.2 Experiments with Mortars

The consistency of the mortar mixes was determined by measuring the increase in the base diameters of the mortars molded over a flow table. The mixing ratio was 1 part cement, 2.75 parts standard sand and 0.485 part water. The effects of mixing with sea waters were slight and inconclusive.

Prismatic mortar specimens 4 x 4 x 16 cm in dimensions were loaded at center points to determine the flexural strength. The mixing ratio was 1 part cement, 3 parts standard sand and 0.5 part water. Moist curing was applied. The results are shown in Table 4.

The compressive strength of the mortars was determined over the broken halves of the flexure specimens by applying the load through 4 x 4 cm steel plates. The results are given in Table 4.

The sulfate resistance of mortar mixes were investigated over cubic specimens having 5 cm dimensions. Material proportions were same as in consistency test. For each mix the specimens were moist cured for the first 28 days. At this age one group of specimens were tested for compressive strength, the second group was immersed in the mixing water used and the third group was immersed in 10% sodium sulfate solution. The

Table 4. Flexural and Compressive Strengths of Mortars

Mix	Flexural (kgf/cm <sup>2</sup> )			Compressive (kgf/cm <sup>2</sup> )		
	7 day	28 day	90 day	7 day	28 day	90 day
To	65	80	91	256	324	432
Bo	72	84	90	311	347	458
Mo	72	85	90	297	420	449
Meo	67	85	96	283	413	473
Ts	56	74	80	226	337	432
Bs	69	83	87	270	350	469
Ms	64	76	82	237	325	447
Mes	63	79	89	276	348	516
Tt	46	60	69	184	252	343
Bt	56	66	68	217	290	354
Mt	51	63	72	200	280	364
Met	59	69	73	246	293	401
Ta	49	56	61	183	248	308
Ba	53	64	70	225	263	369
Ma	49	63	70	238	300	380
Mea	65	70	75	256	324	393

specimens in the last two groups were tested for compressive strength at the end of 316 days. The results are shown in Table 5.

Table 5. Compressive Strengths in Sulfate Resistance Test (kgf/cm<sup>2</sup>)

Mix	28 day	316 day in		Mix	28 day	316 day in	
		water	sulfate			water	sulfate
To	227	323	193	Tt	186	263	225
Bo	237	328	225	Bt	196	280	242
Mo	279	377	232	Mt	203	268	254
Meo	280	364	212	Met	200	279	250
Ts	221	327	228	Ta	180	258	220
Bs	223	328	239	Ba	194	272	230
Ms	225	324	220	Ma	212	301	248
Mes	230	335	229	Mea	221	312	214

The corrosion of steel bars embedded in mortar was studied over cubic specimens having 15 cm dimensions. They were prepared from 1 part cement, 6 parts coarse sand and 0.55 part water. Each contained two steel bars having 12 mm diameters and 14 cm lengths. The bars were arranged so that one had 2 cm and the other 4 cm mortar cover. Due to mix proportions and loose compaction the specimens were relatively porous. After 28 days of moist curing they were placed in 3.5% sodium chloride solution up to their mid depths with bars in vertical position. The specimens were removed from the solution after 285 days. The bars were cleaned off any rust and weighed to determine the weight losses. The results are given in Table 6.

Table 6. Corrosion of Steel Bars in Mortar

Mix	Mortar cover (cm)	Weight loss (%)	Mix	Mortar cover (cm)	Weight loss (%)
To	2	0.733	Tt	2	0.536
	4	0.688		4	0.405
Meo	2	1.516	Bt	2	1.095
	4	1.040		4	0.925
Ts	2	0.391	Met	2	1.120
	4	0.390		4	1.053
Bs	2	0.939	Ta	2	0.527
	4	0.871		4	0.464
Mes	2	1.336	Ba	2	0.933
	4	1.260		4	0.870
			Mea	2	1.177
				4	1.143

### 3.3 Experiments with Concretes

For all concrete properties tested the material quantities in the mixes, in  $\text{kg/m}^3$ , were as follows: cement: 300, net water: 150, fine sand: 377, coarse sand: 453, fine gravel: 491, coarse gravel: 566.

The air content of the fresh concrete was determined by the pressure method, using an air meter. Mixing with sea waters did not effect the results.

The workability of the fresh concrete was determined by the slump test. The values ranged from 2.5 to 5 cm according to cement type. Again, mixing with sea waters did not have significant effect.

For determining the compressive and splitting tensile strengths 15 x 30 cm cylindrical specimens were cast from each mix. They were moist cured until the day of testing. The results are shown in Table 7.

The corrosion of steel bars embedded in concrete was studied over prismatic specimens having 15 x 15 x 30 cm dimensions. Each specimen contained four 12 mm diameter bars which were arranged along the 30 cm dimension to have 2, 3, 4 and 6 cm concrete covers. The specimens were cast and compacted carefully and moist cured for the first 48 days. Later, they were subjected to wetting-drying cycles in 3.5% sodium chloride solution, each cycle lasting about one week. After four years, there were no visual signs of corrosion such as staining or cracking over the surface of the specimens.

Table 7. Splitting Tensile and Compressive Strengths of Concretes

Mix	Splitting (kgf/cm <sup>2</sup> )			Compressive (kgf/cm <sup>2</sup> )		
	7 day	28 day	90 day	7 day	28 day	90 day
To	13	19	21	109	179	200
Bo	17	23	24	167	225	275
Mo	15	20	24	168	231	278
Meo	17	20	23	175	248	289
Ts	11	18	21	101	184	220
Bs	13	17	22	137	203	222
Ms	14	18	22	139	192	225
Mes	12	18	20	152	215	265
Tt	8	12	16	83	125	174
Bt	8	14	18	101	147	177
Mt	8	14	15	89	139	176
Met	10	14	19	107	155	187
Ta	11	14	17	111	162	215
Ba	10	14	20	113	164	223
Ma	11	16	20	132	175	241
Mea	12	16	19	141	196	258

#### 4. DISCUSSIONS AND CONCLUSIONS

The sea waters used in the experiments represented a good range of salinity. The cements generally complied with the related Turkish standards. However, SO<sub>3</sub> content of ordinary portland cement was slightly higher than 3% allowable. Trass cement had a lower 28-day compressive strength than the minimum required 325 kgf/cm<sup>2</sup>. Its ignition loss was also higher than 3% allowable. The chemical compositions from Table 2 indicate usually low CaO and high Al<sub>2</sub>O<sub>3</sub> contents, especially for ordinary portland cement. This could be due to improper raw materials, additions and insufficient calcination. All cements. were ground finer than the minimum required values of 220-280 m<sup>2</sup>/kg.

Mixing with sea water did not have significant influence on the consistency of pastes, mortars and workability and air content of concretes. Sea waters also did not affect the soundness of the pastes indicating that they did not have volume-expanding effects on cements.

A study of Table 3 indicates that with all cements sea waters accelerated both the initial and the final setting times and caused slightly higher heats of hydration. They also reduced the porosity of the hardened pastes slightly. Shortening of the setting times were in proportion with the salinity and could be as much as by 22% in the case of Mediterranean water mixed with trass cement.

Mixing with sea waters increased the mortar and concrete compressive strengths at 7, 28 day and 90 days by 15-25%. As seen from Tables 4 and 7, larger increases were obtained with Mediterranean water indicating some proportionality with the salinity. No definite relation could be established between cement type and strength increases. Sea waters caused smaller increases in the indirect tensile strengths of mortars and concretes.

Above effects of the sea waters could be explained by the presence of NaCl as the main salt in the sea water. An x-ray diffraction analysis of the pastes mixed with sea waters indicated its separate crystallization without changing the regular hydration products [7]. It was also reported that when NaCl was present in the medium tricalcium silicate could hydrate faster [8]. Although the effect of NaCl on heat of hydration and strength is variable [9], the test results confirm its role as an accelerator at least for the salinity ranges and cements involved in the program. Faster hydration with sea water produces more hydration products which start filling the pores in the paste earlier contributing to relatively higher strengths. Smaller increases in the indirect tensile

strengths indicate that NaCl crystals forming in the pores may also contribute to larger increases in compressive strength.

According to the strength changes in Table 5 mortars seem to have higher sulfate resistance with trass cement and lower with admixed cement. The effect of sea water mixing is not very conclusive, possibly due to a balance between the chemical reactions involved. Sodium chloride in the sea water increases the solubility of free lime and calcium sulphoaluminates thus, decreasing sulfate corrosion. On the other hand, sulfate concentration in the medium is increased because of the sea water.

Mixing with sea waters increased the corrosion of steel bars embedded in loosely compacted mortars. As shown in Table 6 weight losses were highest with Mediterranean water. Increasing the bar covers from 2 to 4 cm was not sufficiently effective. However, steel bars embedded in dense concrete did not exhibit visual signs of corrosion after four years. It is known that normally a protective iron oxide or hydroxide layer forms over the steel bars embedded in concrete due to alkalinity of the medium. Penetration of chlorides lowers the pH value of the medium and the protective layer is destroyed. Test results obtained so far can be explained by a similar mechanism.

In conclusion, it can be stated that as mixing water sea waters do not have significant influence on the consistency, workability and air content of mortars and concretes. They shorten both setting times, cause slightly higher heat of hydration and some acceleration in the formation of hydration products, followed by increased strengths up to 90 days. Strength increases are not very much on the average and such concretes may be proportioned in the usual manner. As in all marine environments concrete should be dense and sufficient bar cover must be provided. In hot climates precautions may be required against accelerated setting.

Similar research with local materials is recommended, especially if the properties of the local materials are considerably different from those used in the study. Such information as well as the findings of this study can contribute towards making more rational decisions on using the sea waters for concrete mixing considering all the technical and economical aspects. Additional information would also be useful for better understanding the sulfate resistance and long-term strengths of such concretes. At present such a study is underway at Jordan University of Science and Technology involving the concretes mixed with the Red Sea water (which has higher salinity than Turkish sea waters) and containing Jordanian cements.

#### REFERENCES

1. Abrams, D.A. (1924), Effect of Impure Waters When Used in Mixing Concrete. Proc. ACI, 20, 442-486.
2. Taylor, M. and Kuwairi, A. (1978), Effects of Ocean Salts on the Compressive Strength of Concrete. Cem. Conc. Res., 9.
3. Griffin, D.L. and Henry, R.L. (1963), Proc. ASTM, 63, 1046-1078.
4. Shalon, R. and Raphael, M. (1959), Influence of Sea Water on Corrosion of Reinforcement. J. ACI, June, 1251-1268.
5. TS 1247, (1973), Mixing, Placing and Curing of Concrete. Ankara, Turkey.
6. TS 500. (1981), Building Code Requirements for Reinforced Concrete. Ankara, Turkey.



7. Yeğınobalı, A. and Cebeci, O. (1981), TBTAK, Report No. 508, Ankara, Turkey.
8. Young, J.F. and Tong, H.S. (1977), Compositions of Solutions in Contact with Hydrating Tricalcium Silicate Pastes. J. Am. Ceram. Soc., 60.
9. Neville, A.M. (1977), Properties of Concrete. Pitman, 97.

