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Cement & Concrete Composites 27 (2005) 33–39
Cement & Concrete Composites
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Effect of water quality on the strength of flowable fill mixtures

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Received 17 February 2003; accepted 26 January 2004

Abstract

Fresh water is a precious and scarce commodity in all arid regions such as Oman and other parts of the Arabian Peninsula. However, non-fresh water supplies including brackish groundwater and oily water that accompanies oil production activities, and treated wastewater exist in abundant quantities in these regions. A flowable fill, also known as a controlled low strength material, is a self-compacted, cementitious material used primarily as a backfill. It is generally a mixture of fine aggregates, small amount of cement, fly ash, and water. This paper discusses the potential use of groundwater and oily production water in flowable fills. The water used in this research work was obtained from four major oil production fields. Cement by-pass dust (CBPD) was used as an alternative to fly ash. Results indicate that the use of non-fresh water will produce lower compressive strength in comparison with tap water. However, all water types would still generate an acceptable 28-day strength requirement of 350–3500 kPa for flowable fills. With the exception of a few mixes, flowable fill blends prepared using brackish groundwater gave higher strength than mixes prepared using oily production water. Generally, there was no appreciable difference in slump values for most of the mixes.

Keywords: Flowable fill; Groundwater; Oily water; Waste material; Portland cement; Cement by-pass dust; Cement kiln dust

1. Introduction

1.1. Background

The Sultanate of Oman lies in an arid region where fresh water sources are scarce. Economic and population growth spur the need for more housing, schools, roads and many other civil works. In the construction of such projects, water is needed as a component in concrete mixtures. It is primarily needed for the hydration process of cementitious materials and for curing. Water is also needed for road construction projects, where it is used as mixing water for compaction and for dust control. Contractors in arid regions, and especially in remote areas of the desert, are sometimes faced with the problem of finding water of acceptable quality for their construction work. However, plenty of water is produced in the oil fields during oil exploration. Water produced with oil forms the largest waste in the entire oil production business. An oil field is expected to produce more than ten times the amount of water as that of oil during its economic life [1]. In a recent year, about 450,000 tons/day of water is produced along with an oil production of 135,000 m^3/day in Oman [2]. This wastewater is injected back underground for reservoir pressure maintenance and/or disposed off into shallow and deep reservoirs. It is essential to investigate the feasibility of using this water in construction.

1.2. Water quality

Water quality has been a matter of concern in civil engineering construction [3,4]. Most specifications require the use of potable water because its chemical composition is known and well regulated. In some situations where potable water is not readily available, many water types which are unacceptable for drinking may be satisfactorily used in concrete, road construction and other applications [5]. The performance requirements in British Standards [6] and AASHTO T26-79 [7] are the time of setting and the compressive strength. A note in the British Standard [6] requires that the compressive strength of concrete cubes made of untried water not to be less than 90% of cubes made with tap water. The note also states that water that results in a strength reduction of up to 20% can be acceptable, but the mixture proportions should be adjusted as

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doi:10.1016/j.cemconcomp.2004.01.005

appropriate. The physical and chemical requirements in the standards refer to dissolved salts and solids in suspension. AASHTO T26-79 [7] prescribes test methods for the pH value in water as well as testing for chloride, sulfate, organic and inorganic contents.

The literature search indicated that not much research work was performed on the effect of water quality on the properties of flowable fills. However, various sources of non-fresh water including sea and alkali waters, mine and mineral waters, waters containing sewage and industrial wastes, wastewater produced from ready-mixed concrete plants, and solutions of common salt were previously tested for use in concrete mixtures [8–11]. It is difficult to draw a common conclusion regarding the use of these waters in concrete mixtures since impurities that exist in each water type are different. However, the general consensus is that there is a reduction in the ultimate strength of concrete when impure water is used. But with proper mix design (such as use of more cement and use of cementitious materials and admixtures) and by using some acceptable tolerance limits, it is possible to use impure water in concrete mixing and curing. However, there may be a higher risk of steel corrosion when non-fresh water is used in reinforced concrete.

1.3. Flowable fills

A flowable fill is a slurry or semi-fluid material consisting of a mixture of cement, sand, water and a by-product material (usually fly ash) [12]. Other common names include controlled low strength material (CLSM), controlled density fill (CDF), K-Krete, and unshrinkable fill. Flowable fills are characterized by very high workability and low density and strength, which allow self-compaction. They are widely used in backfilling applications and other road-cuts, but can also be used for road bases, mud slabs and slope stabilization. Fly ash is widely used in flowable fill mixes in order to reduce the cost and ensure low compressive strengths. Other waste materials used in flowable fills include ground granulated blast furnace slag (ggbfs) and waste foundry sand (WFS) [13].

The beneficial use of by-products (coal fly ash, ggbfs, silica fume, etc.) in concrete technology has been well known for many years and significant research papers have been published regarding the use of such materials as a partial replacement for Portland cement. Such concrete mixtures are widely used in the construction of industrial and chemical plants because of their enhanced durability and economical benefits. One of the materials that is considered as a waste material and which could have a promising future as a partial Portland cement or fly ash replacement is cement by-pass dust (CBPD) [14]. Utilization of CBPD in applications such as Portland cement substitution and/or as a cement raw material has three fold advantages of eliminating the costs of dumping, reducing the cost of concrete, and minimizing air pollution problems. The authors have published results [15,16] of an investigation on the use CBPD as a cement replacement in flowable fill applications.

A flowable fill reduces construction costs since no vibration or tamping is required to compact the material as well as it limits settlement and eliminates maintenance costs. Other benefits gained from using flowable fills are improved worker safety because trench exposure is limited, better durability because it is less permeable than compacted granular backfills, and it can be used in hard-to-reach places. For design and application purposes, flowable fill materials usually have a compressive strength of about 8.3 MPa (1200 psi) or less. However, most current flowable fill applications require a 28-day compressive strength of 0.7 MPa (100 psi) [17]. The lower strength requirement allows for future excavation with conventional excavation equipment.

2. Objective

The main objective of this paper was to investigate the effect of water quality on the properties of flowable fill mixtures. The following were specific tasks:

(1) Perform chemical and physical characterization of the water used.
(2) Conduct compressive strength testing on various flowable fill mixtures.

3. Materials

3.1. Sand

The fine sand was purchased from a nearby crusher in Al-Khoudh area, which is from the same batch used in normal concrete mixtures. The gradation test conducted on the sand showed that it met specifications requirements. Percent passing 75 μm (No. 200 sieve) was 5%.

3.2. Cement

The cement used in this project was ordinary Portland cement (OPC) purchased from Oman Cement Company. This cement is the most widely used one in the construction industry in Oman.

3.3. Cement by-pass dust (CBPD)

CBPD is a by-product of the manufacture of Portland cement. It is generated during the calcining process in the kiln. As the raw materials are heated in the kiln, dust particles are produced and then carried out with the

Table 1
Chemical and physical composition of ordinary Portland cement and cement by-pass dust

Component	Ordinary Portland cement (%)	Cement by-pass dust (%)
SiO_2	21.95	15.84
Al_2O_3	4.95	3.45
Fe_2O_3	3.74	2.98
CaO	62.33	59.26
MgO	2.08	2.11
SO_3	2.22	2.00
K_2O	0.56	2.99
Na_2O	0.32	0.60
TiO_2	0.17	NA
Mn_2O_3	0.05	NA
Cl^-	0.01	0.91
Loss on ignition	1.78	9.67
Insoluble residue (IR)	0.24	NA
Fineness (m^2/kg)	335.7	482.4
Specific gravity	3.05	2.4
Initial setting time (min)	110	150

exhaust gases at the upper end of the kiln. These gases are cooled and the accompanying dust particles are captured by efficient dust collection systems. Composition of CBPD is quite variable from one source to another due to raw material and process variations. Physical properties and chemical composition of Portland cement and CBPD are presented in Table 1. The high alkali content (K_2O) in CBPD can cause alkali silica reaction (ASR) in concrete. However, the addition of very small amount of CBPD in flowable fill mixtures is not expected to cause ASR especially when the sand used in the mix is free from reactive materials.

3.4. Mixing water

Water samples were obtained from four major oil fields in Oman (Rima, Bahja, Nimr, and Marmul). These samples represent both groundwater and production water (oily). A total of 18 water samples (including tap water) were collected in 2001 and 2002 and analyzed for certain impurities that could affect concrete or slurry mixes. Measurements included: total alkalinity (as $CaCO_3$), sulfate content (as SO_4), chloride content (as NaCl), total dissolved solids and water hardness. Other parameters such as pH and conductivity were also measured. Table 2 presents the chemical analyses obtained on all samples. The analysis was conducted in the laboratories of the Ministry of Housing, Electricity, and Water in Oman.

For the groundwater samples collected in 2001, the Marmul water is the closest in terms of its quality to tap water. However, the Bahja groundwater samples collected in 2002 seem to have the best quality of all water samples. The Bahja production water collected in 2001 seems to have the highest salinity. Groundwater samples obtained from other sites were generally salty. There were differences in groundwater quality between the four Petroleum Development of Oman (PDO) sites. Similarly, the quality of production water was variable from one site to another. As shown in Table 2, the quality of production water collected in 2001 and 2002 were different from each other. This indicates that the quality of production water in each site is variable with time. Less variability was generally observed between the groundwater samples collected from the same area. The results also show that the quality of groundwater and production water obtained from the same site were different. This result is expected since these waters come from different depths.

4. Mix design

4.1. Sample preparation

Coal fly ash is an important ingredient used in flowable fill mixes. In Oman, coal fly ash is not available and CBPD was used as a replacement for either Portland cement or fly ash. Eighteen mixes were prepared and they were assembled in three groups (A, B, and C). All mixes were cured at room temperature. A description of the three groups is as follows:

- Group A: these are the control mixes prepared using tap water and include two mixes which are designated as Mix 1 and Mix 2. They were prepared using tap water, sand, ordinary Portland cement (OPC), and cement by-pass dust. Mix 1 contains cement by-pass dust in addition to OPC, while in Mix 2 OPC is fully replaced by cement by-pass dust. Table 3 shows the mix design for Group A.
- Group B: these contain OPC, cement by-pass dust, sand and water. The mix design is the same as that of Mix 1. However, tap water was replaced by groundwater and production water collected in 2001.
- Group C: these contain cement by-pass dust, sand and water. The mix design is the same as that of Mix 2. However, tap water was replaced by non-fresh water collected in 2001 (similar to Group B).

Table 4 shows a description of all mixes.

For all mixes, 70-mm cubes were cast for compressive strength testing. The samples were kept in the moulds for 24 h and then demoulded and cured at room temperature for 7, 14, 28, and 56 days. Triplicate specimens were prepared for each mix and curing period. Samples were not cured in a water tank since the strength of a flowable fill mix is extremely low and could easily crumble upon placement in water. All samples were prepared and tested in accordance with ASTM standards. For unconfined compressive strength testing, the rate of load application used was 0.1 kN/s.

Table 2
Water quality analysis for samples from Petroleum Development of Oman sites

Source of sample	Sample label	Time of sample collection	Parameter concentration					
			PH	TDS (mg/L)	Chloride (mg/L)	Hardness (mg/L)	Alkalinity (mg/L)	Sulfate (mg/L)
Tap water	TW	2001	8.6	278	75	94	58	278
		2002	8.3	398	86	182	114	65
Bahja groundwater	BG	2001	6.7	8770	5100	670	55	7.5
		2002	8.2	233	93	17	16	5
Bahja production water	BP	2001	7.4	66,300	44,500	13,000	59	281
		2002	7.3	9720	4790	1320	94	662
Rima groundwater	RG	2001	7.9	10,960	5420	1730	134	826
		2002	7.4	9850	4820	2250	169	759
Rima production water	RP	2001	8.0	11,540	5850	880	240	323
		2002	8.5	586	223	13	72	5
Marmul groundwater	MG	2001	8.0	1360	331	558	100	281
		2002	8.0	1540	383	588	147	548
Marmul production water	MP	2001	7.3	4900	2040	166	606	233
		2002	8.3	4220	2080	146	80	<1
Nimr groundwater	NG	2001	7.6	7080	3080	1680	209	982
		2002	7.8	7050	3160	1670	219	782
Nimr production water	NP	2001	7.3	423	4000	490	399	330
		2002	7.9	8200	138	23	95	15

TDS: total dissolved solids.

Table 3
Mix design for Group A samples (control mixes)

	Mix 1	Mix 2
Cement (kg/m^3)	47	0
Cement by-pass dust (kg/m^3)	249	296
Sand (kg/m^3)	1503	1503
Water (kg/m^3)	333	333
W/C	7.09	0.00
W/(C + CBPD)	1.13	1.13
Slump (mm)	248	235
28-day strength (MPa)	2.735	1.074

Table 4
Description of mixes

Mix group	Mix designation	Water source
Group A (control)	1	Tap water
	2	Tap water
Group B	BG	Bahja (ground)
	BP	Bahja (production)
	NG	Nimr (ground)
	NP	Nimr (production)
	RG	Rima (ground)
	RP	Rima (production)
	MG	Marmul (ground)
	MP	Marmul (production)
Group C	BG	Bahja (ground)
	BP	Bahja (production)
	NG	Nimr (ground)
	NP	Nimr (production)
	RG	Rima (ground)
	RP	Rima (production)
	MG	Marmul (ground)
	MP	Marmul (production)

5. Test results and discussion

5.1. Group A (control mixes) strength results

Fig. 1 shows the unconfined compressive strength results obtained for the control mixes (Group A). Both mixes have their 28-day strength values within the rec-

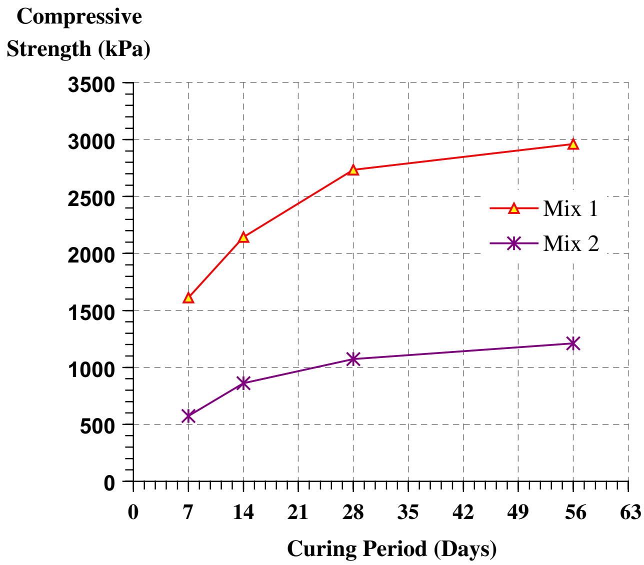

Fig. 1. Unconfined compressive strength for the control mixes (Group A).

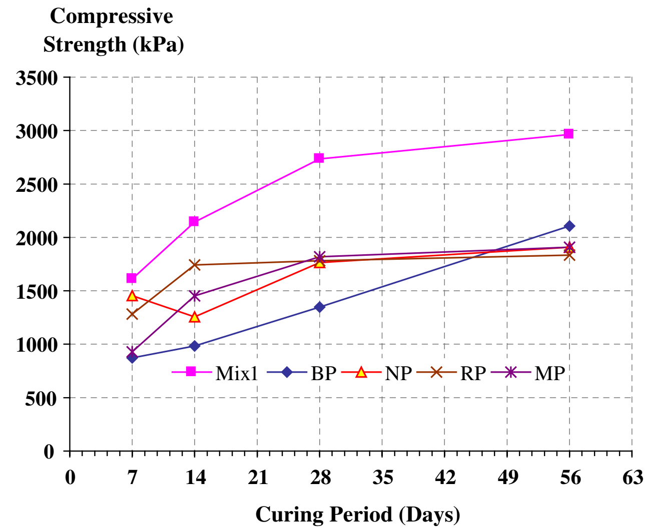

Fig. 3. Strength comparison among production water mixes (Group B) and Mix 1.

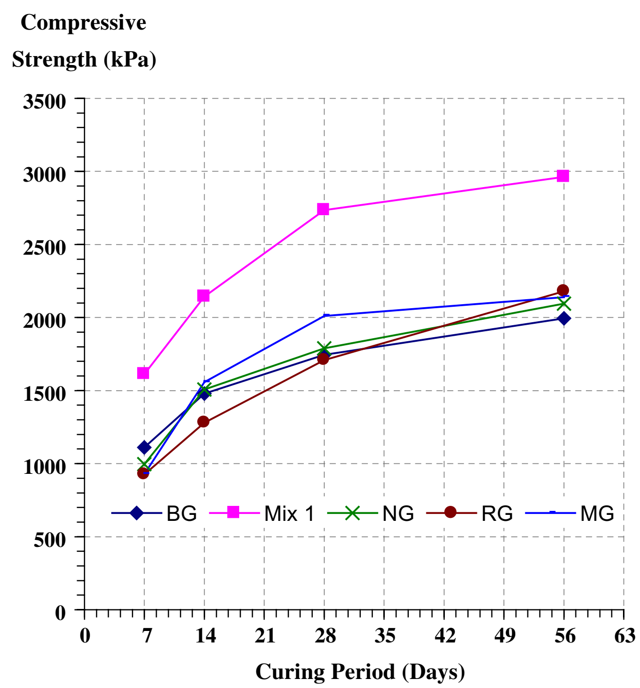

Fig. 2. Strength comparison among groundwater mixes (Group B) and Mix 1.

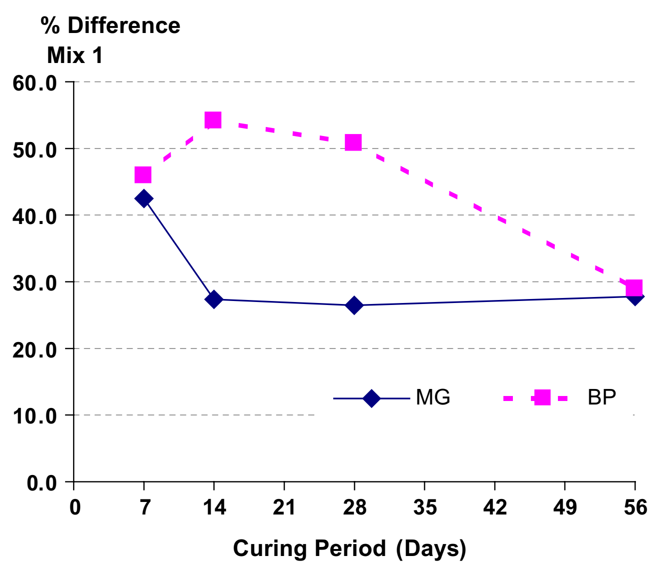

Fig. 4. Comparison of percent strength difference of mixes prepared using Bahja production and Marmul groundwater with Mix 1.

ommended limits (0.35–3.5 MPa) and less than 8.3 MPa as required by ACI Committee 229 [17].

5.2. Group B strength results

Fig. 2 shows a comparison of compressive strength results among fresh water mixes (Group B) with Mix 1, while Fig. 3 shows the comparison among the production water mixes with Mix 1. Fig. 4 shows the percent strength differences for the strongest and weakest mixes with the control mix (Mix 1). The results indicate that:

1. All Group B mixes gave strength values that are lower than the strength of Mix 1 for all curing periods.
2. Groundwater mixes generally gave slightly higher strength values than production water mixes.
3. In general, the Marmul groundwater mix gave the highest strength of all Group B mixes while the Bahja production water mix gave the lowest strength. This

somehow correlates well with the quality of water used in such mixes (Section 3).
4. Although all water types would still yield an acceptable 28-day unconfined compressive strength for flowable fills (greater than 0.35 MPa), Fig. 4 shows that the strength difference was high and ranged from about 25% to 55%. However, Fig. 4 also shows that the difference in strength decreases with an increase in curing period. The initial difference increase for the mix with Bahja production water could be attributed to the high Cl^- contents in the mixing water.
5. The slump values obtained for all mixes were acceptable (above 200 mm) and near each other. The only exception is Nimr production water where a slump value of 120 mm was measured.

5.3. Group C strength results

Figs. 5 and 6 shows a comparison of compressive strength values among Group C mixes and Mix 2 for groundwater and production water, respectively. Fig. 7 shows the percent strength differences for the strongest and weakest mixes with the control mix (Mix 2). The results indicate that:

1. Generally for curing periods of 7, 14, and 28 days, all Group C mixes have strength values less than Mix 2. The exceptions are Marmul production water and Rima groundwater.
2. Marmul production, Nimr production, and both Rima groundwater and production water gave 56-day strength values higher than Mix 2.
3. Groundwater mixes gave a slightly higher strength than production water mixes. The exception is Marmul production water.

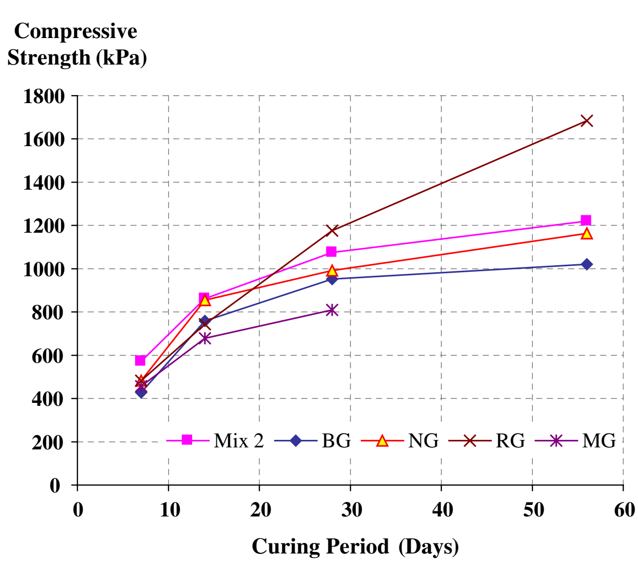

Fig. 5. Strength comparison among groundwater mixes (Group C) and Mix 2.

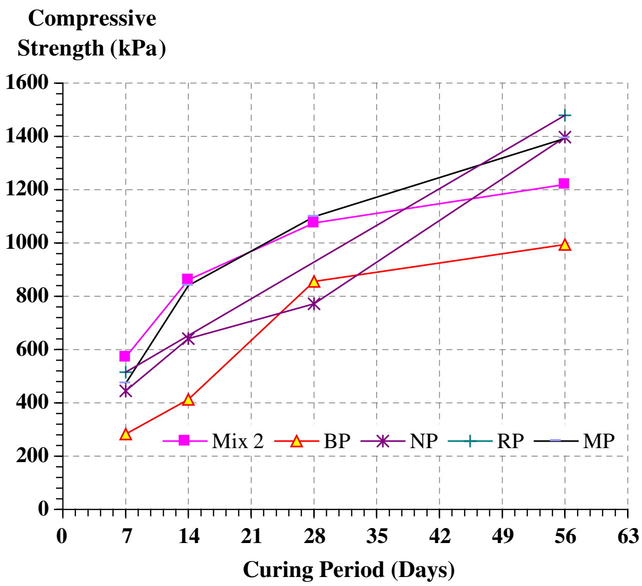

Fig. 6. Strength comparison among production water mixes (Group C) and Mix 2.

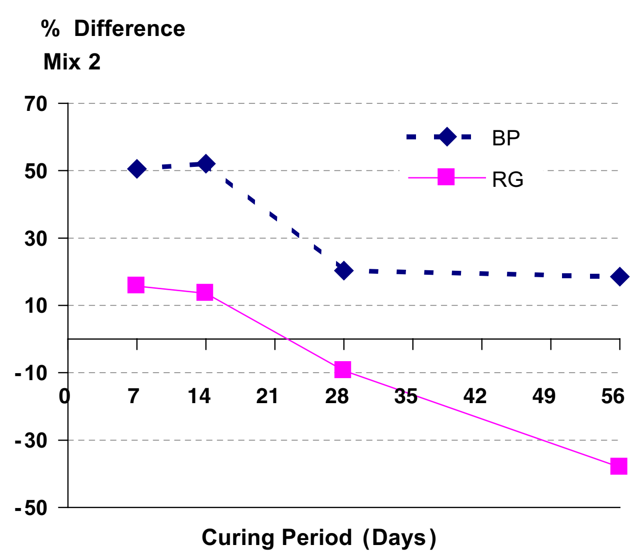

Fig. 7. Comparison of percent strength difference of mixes prepared using Bahja production and Rima groundwater with Mix 2.

4. All water types would still yield an acceptable 28-day unconfined compressive strength for flowable fills (greater than 0.35 MPa).
5. The slump values obtained for all mixes were acceptable (greater than 200 mm).

6. Conclusions

This study evaluated the use of non-fresh water in flowable fill mixes. A total of nine water types were investigated. Various mixtures were evaluated using Portland cement, cement by-pass dust, sand, and water. The results indicate that the use of non-fresh water (groundwater and production waters) will yield lower compressive strength in comparison with tap water. However, such water types would still generate an acceptable 28-day strength requirement of 0.35–3.5 MPa for flowable fill mixes. With the exception of few mixes, flowable fill blends prepared using groundwater gave higher strength than mixes prepared using production water. In general, there was no appreciable difference in slump values obtained for most of the mixes.

Acknowledgements

The authors would like to express their gratitude to Petroleum Development Oman (PDO) for providing financial support to the project under contract CTR No. 2001.21. Thanks are particularly due to Mr. Tan Gung Tuang, Head of Environmental Affairs for his support and encouragement. Oman Cement Company is also acknowledged for their cooperation and support.

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