Disposal of Sea Bottom Sediments by Use as Raw Material for Concrete Elements

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ABSTRACT

The possibility of using sea bottom sediments as a substitute for fine sand aggregate was investigated for the fabrication of concrete solids and marine reefs. The proportions of raw materials in the concrete mixture were optimized, and the materials were evaluated with by testing their slump, air content, mass change, total shrinkage and compressive strength. In the short term, i.e. a curing age of 3 to 28 days, the compressive strengths of the concrete materials made with the sediments were better than those of the normal concrete blocks. Furthermore, after 187 days of curing, the compressive strengths were 44, 31 and 12 MPa respectively for the concrete products with a water-cement ratio (w/c) by weight of 0.47, 0.69 and 1.15 using the sediments. When the concrete materials were field-tested in the sea for approximately one year, the blocks were not damaged by the sea environment because the compressive strengths were 48, 33 and 14 MPa with w/c = 0.47, 0.69 and 1.15, respectively. Since the concrete blocks constructed with the optimal mix of raw materials had enough solid strength to be used in the sea, it may be unnecessary to add steel reinforcement to this concrete for the specific purpose of constructing marine reefs.

Keywords: Concrete, sea bottom sediments, compression, slump, shrinkage, marine reefs

1. INTRODUCTION

The corrosion resistance of concrete is one of the most important factors in the durability of this material. Chloride ions constitute one of the deleterious agents that may cause or promote corrosion of steel reinforcement in concrete. Chloride-induced corrosion of steel reinforcement in concrete structures has been a focus of interest for decades in the field of civil engineering. As a result, a number of investigators have dealt with the influence of chloride ions on the qualities of cement (Shi et al., 2000a; Shi et al., 2000b; Koleva et al., 2006).

Ago Bays in Mie prefecture, Japan is world-famous area as the origin of pearl and oyster culture. However, there is a concern that the sea conditions have recently become worse due to the culturing of pearls and oysters, which has resulted in the accumulation of organically-enriched sediments on the sea bottom. Therefore, dredging of sea sediments has been performed since 2000, so as not to worsen the sea quality in Ago Bays. Since the dredged sea sediments have a horrible smell, the limited availability of suitable disposal places has become a serious problem. Hence, developing cost-effective, environmentally sound and sustainable management alternatives for the dredged material is a critical issue for the continued operations of the pearl and oyster culture industry' in these bays, which contribute significantly to the Japanese industry (Kaneco et al., 2004, 2005; Katsumata et al., 2004; Imai et al., 2007; Dabwan et al., 2007).

One solution being discussed is to manufacture bricks from the sea sediments. This concept gives priority to waste recovery over its deposit in landfills. The technology of producing bricks from harbour sediments was reviewed as a possible concept for sediments in Bremen (Hamer et al., 1999). On the other hand, there is little information on the fabrication of concrete solids using sea sediments as raw materials, due to the corrosion of the steel reinforcement. Recently, Alabadan et al. (2006) have investigated the potentials of groundnut shell ash (GSA) as a partial replacement for ordinary Portland cement in concrete. In the study, although the strength of the control was higher, the replacement of cement with ash up to 30% would be more suitable than others.

If the solid strength of cement is improved by optimizing the raw material components, it may be unnecessary to add the steel reinforcement to the concrete for certain purposes. The present work presents the possibility of using sea bottom sediments and the optimization of the raw material components for the fabrication of marine concrete reefs. This application deals with the utilization of sea bottom sediments as a substitute for fine sand aggregate.

2. MATERIALS AND METHODS

2.1 Dredged Sea Sediments

The sea bottom sediments in Ago Bay were dredged and collected in March, 2005. The typical chemical components in the sediment were as follows: SiO_2 (51.0%), Al_2O_3 (17.2%), CaO (11.9%), SO_3 (9.6%), Fe_2O_3 (4.5%), K_2O (3.1%), MgO (1.8%) and TiO_2 (0.6%). The main chemical components of the sediments dredged in the present work were very similar to those reported previously in Ago Bay (Kaneco et al., 2004), and the concentrations of toxic metal elements, including lead, cadmium and arsenic, were not a serious problem. Moreover, toxic organic pollutants such as agrochemicals, pesticides and dioxin were not detected in the sediments. The chloride content was 1.63 wt% in the dried sediments. The water content of the dredged sediments was 90% by weight. The "Hi-Biah-System (HBS)" for the in-situ solidification of sediments, was used for the treatment of the sediments (Imai et al., 2007; Dabwan et al., 2007). The HBS consisted of a main stock tank for the sediments, a coagulant chamber, reactors and a dewatering section. The treatment capacity was approximately 1~2 m^3/hour. The soil conditioner (1.5 wt%), made of the ash from burning paper sludge, was used as the coagulant in the HBS. The chemical components of the soil conditioner were CaO 44.2%, SiO_2 26.9%, Al_2O_3 12.7% and SO_3 12.2 %. After treatment with the HBS, the water content was reduced to 60% by weight.

2.2 Fabrication of Concrete

The raw materials used in the fabrication of concrete were as follows: Portland blast-furnace slag cement (B, Ube-Mitsubishi Cement Corp., density 3.05 g/cm^3, JIS R5211 (JIS 2003), Chemical component: SiO_2 25.29%, Al_2O_3 8.46%, Fe_2O_3 1.92%, CaO 55.81%, MgO 3.02%, SO_3 2.04%, Na_2O 0.25%, K_2O 0.39%, TiO_2 0.43%, P_2O_5 0.12%, MnO 0.05% and Cl 0.003%, ignition loss 1.51%, insoluble 0.21%), fine sand aggregate (S, density 2.58 g/cm^3, fineness modulus 2.69), coarse aggregate (G, crushed rocks, density 2.68 g/cm^3, solid content 60 vol%), sea bottom sediments treated with HBS (water content 60 wt%, density 1.34 g/cm^3, solid particle density 2.69 g/cm^3) and additive agents (antiforming agent AFK−2, water-reducing agents EX−50 and SSP−104, Takemoto Oil & Fat Co., Ltd.). The mix proportions of the raw materials are shown in Table 1. Each volume for the raw material components such as cement, sand aggregate, coarse aggregate, water and sediments was changed and adjusted, in order to make their total (sum) volumes 990 dm^3/m^3. The following mixing procedures were selected. For Sample No. 1: the additive agents were added to the running water, and the cement and the fine sand aggregate were mixed with the water for 30 sec, then crushed rocks were mixed in for 90 sec. For Samples No. 2, 3, 4: a method similar to No. 1 was used, except that the cement, fine sand aggregate and sea bottom sediments were mixed with the water for 30 sec. For Sample No. 5: the cement, coarse aggregate and sea sediments were first mixed for 30 sec, then additive agents were added and finally these materials were mixed for 180 sec. For Sample No. 6: the first step was the same as for No. 5, and the water-reducing agent EX−50 was added, followed by mixing for 120 sec. Finally, the additive agent SSP−104 was added to the products. The mixing process was performed with a turbo mixer (TM−55, Pacific Machinery & Engineering Co., Ltd.). The temperature was controlled to a constant 293 K in the environmental room.

2.3 Evaluation of Concrete Products

The slump JIS A 1101 (JIS, 2005a), air content JIS A 1128 (JIS, 2005b), compressive strength JIS A 1108 (JIS, 2005c), total shrinkage JIS A 1129 (JIS, 2005d), and change of mass were checked for the mechanical evaluation of the concrete products (100 × 100 × 400 mm). The surface morphology of the concrete products was analyzed by scanning electron microscopy (SEM, Hitachi S-4000, Japan).

3. RESULTS AND DISCUSSION

3.1 Sediments as a Substitute for Fine Sand

The sea bottom sediments were used as the substitute for fine sand aggregate in this work. Fig. 1 illustrates the grain size distribution of the original sediments and the sediments treated with HBS. It also shows the recommended gradation curves of fine sand aggregates for concrete mixes according to the normal Japanese standard. The gradation of the sediments used falls within the specified gradation limits for fine aggregates.

Table 2. Raw materials for the concrete blocks

No.	Raw material components (kg/m³)									Additive agents (cm³/m³)		
	C[a]	Sediments	Water added	S[b]	G[c]	Total	Water in sediments[d]	Total water[e]	W/C[f]	AFK−2	EX−50	SSP−104
1	420	0	168	759	1045	2392	0	168	0.40	2.8	552	-
2	420	50	168	640	1069	2347	30	198	0.47	2.8	552	-
3	420	100	168	519	1093	2300	60	198	0.53	2.8	552	-
4	420	200	168	248	1174	2210	120	288	0.69	3.3	656	-
5	500	954	0	0	300	1754	572	572	1.14	8.2	1640	-
6	500	1054	0	0	100	1654	632	632	1.26	0	1640	820

[a] cement, [b] fine sand aggregate, [c] coarse aggregate (crushed rocks), [d] water content 60 wt% in sediments, [e] sum of water added and water contained in sediments.

[f] ratio of water to cement by weight.

Table 2. Bulk volume of the coarse aggregate and the sand-total aggregate ratios

No.	G[a] Volume[b] (dm^3/m^3)	G[a] Bulk volume[c] (m^3/m^3)	S[d] (dm^3/m^3)	Sediments (Z) (dm^3/m^3)	S/a[e] (m^3/m^3)
1	390	0.650	294	0	0.43
2	399	0.665	248	37	0.39
3	408	0.680	201	75	0.35
4	438	0.730	96	150	0.22
5	112	0.180	0	714	0.56
6	37	0.600	0	791	0.81

[a] coarse aggregate (crushed rocks), [b] G(kg/m^3)/2.68(g/cm^3), [c] G(kg/m^3)/2.68(g/cm^3)/0.60
[d] fine sand aggregate, [e] sand-total aggregate ratio by volume.
S/a was calculated from the following equation:

$$S/a = \frac{S+0.199Z}{G+S+0.199Z}$$

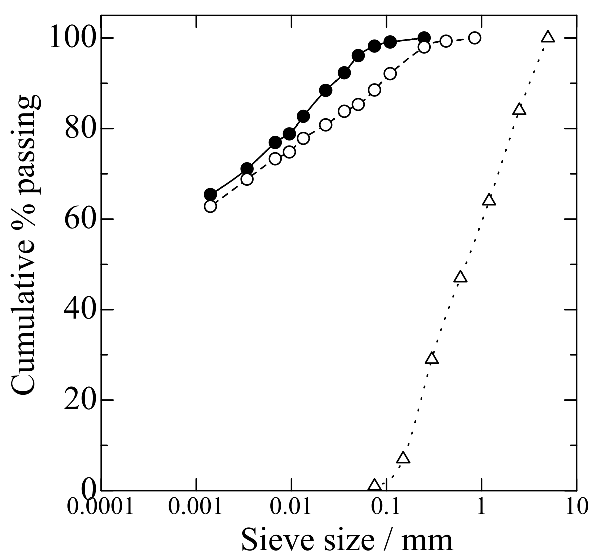

Figure 1. Gradation curves for the original sediments (●), sediments treated with HBS (○) and the fine sand aggregates for the concrete mixes according to the normal Japanese standard (∆).

First, a large variety of mix proportions of raw materials were investigated for the fabrication of concrete products. As a consequence, the useful volume of coarse aggregates was estimated on the basis of the selected bulk volume and solid content (60 vol%) and the volumes for the fine sand aggregates and the sediments were then determined from the difference between the total volume (990 dm^3/m^3) and the sum of the cement, coarse aggregate and water volumes. Finally,

Table 3. Slump and air content of the fresh concrete products

No.	Slump (mm)	Air content (%)
1	72	1.5
2	70	1.7
3	90	1.5
4	79	1.3
5	55	3.5

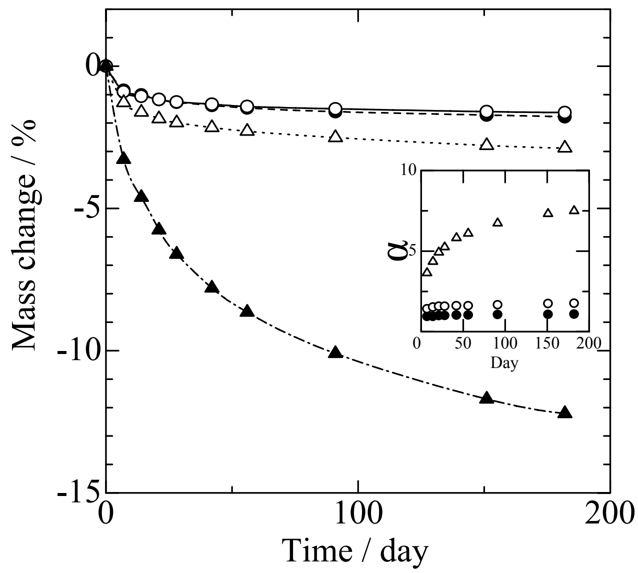

Figure 2. Effect of the water/cement ratio on the mass changes of the concrete products. ○; Sample No. 1 with w/c 0.40, ●; Sample No. 2 with w/c 0.47, △; Sample No. 4 with w/c 0.69 and ▲; Sample No. 5 with w/c 1.15. The insert figure shows α versus the curing age. α was defined as the ratio of mass loss of the concrete materials with the sediments to the mass loss of the normal concrete (sample No. 1). In the insert figure, ●; Sample No. 2, ○; Sample No. 4 and △; Sample No. 5.

five types of raw material components were selected for fabricating the concrete products with sea bottom sediments, as shown in Table 1. The sand-total aggregate ratios by volume for these mix components are presented in Table 2. In the equation in Table 2, a coefficient 0.199 was obtained from the calculation of $1.34 \times 0.4/2.69$. Since the raw concrete materials in Sample No. 6 could not be mixed with the mixer device, it was not possible to use this mix to fabricate a solid product.

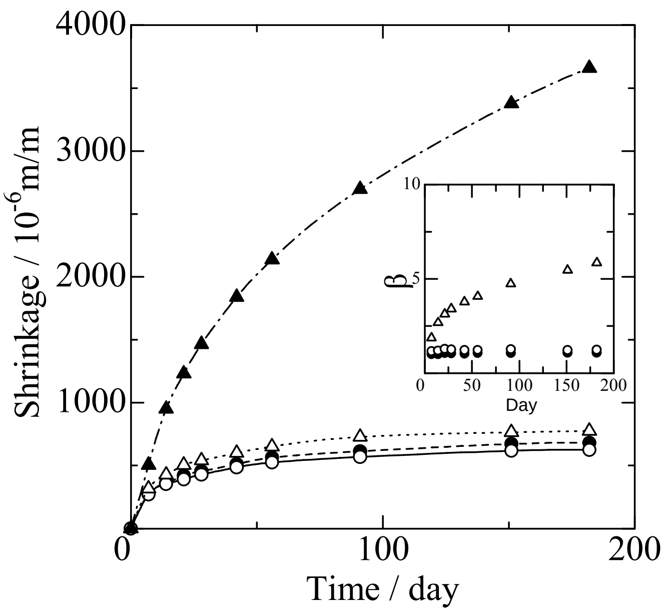

Figure 3. Effect of the water/cement ratio on the total shrinkage of the concrete products. ○; Sample No. 1 with w/c 0.40, ●; Sample No. 2 with w/c 0.47, △; Sample No. 4 with w/c 0.69 and ▲; Sample No. 5 with w/c 1.15. The insert figure shows β versus the curing age. β was defined as the ratio of the total shrinkage of the concrete materials with the sediments to the total shrinkage of the normal concrete (Sample No. 1). In the insert figure, ●; Sample No. 2, ○; Sample No. 4 and △; Sample No. 5.

3.2 Fresh Concrete Products

Slump and air content tests were conducted for the fresh concrete products. The results are presented in Table 3. While the slump was 72 mm in the absence of the sediments (Sample No. 1), it was in the range of 55 to 90 mm in the presence of sediments (Samples No. 2 to 5) and no significant change in the slump was observed when the sediments were used as a substitute for fine sand. The air content in samples with added sediments, except for Sample No. 5, was very similar to that of Sample No. 1.

3.3 Mass Loss and Total Shrinkage

The mass changes of the concrete products over time were investigated. As shown in Fig. 2, all of the samples that lost mass began to lose mass immediately after the construction of the fresh concrete products. The masses of the concrete Samples No. 1, 2 and 4 remained almost constant or decreased very slightly after 56 days. On the other hand, the mass of Sample No. 5 (w/c: 1.15) decreased greatly with time, owing to the evaporation of water from the materials. Here, we define α as the ratio of the mass loss of the concrete materials with the sediments to the mass loss of the normal concrete (Sample No. 1). Although the α value was nearly constant for the concrete materials containing the sediments with w/c = 0.47 and 0.69, it increased when the w/c = 1.14. The results for the total shrinkages of the concrete materials over time are depicted in Fig. 3. The total shrinkage includes both drying and autogenous types. The trends for the total

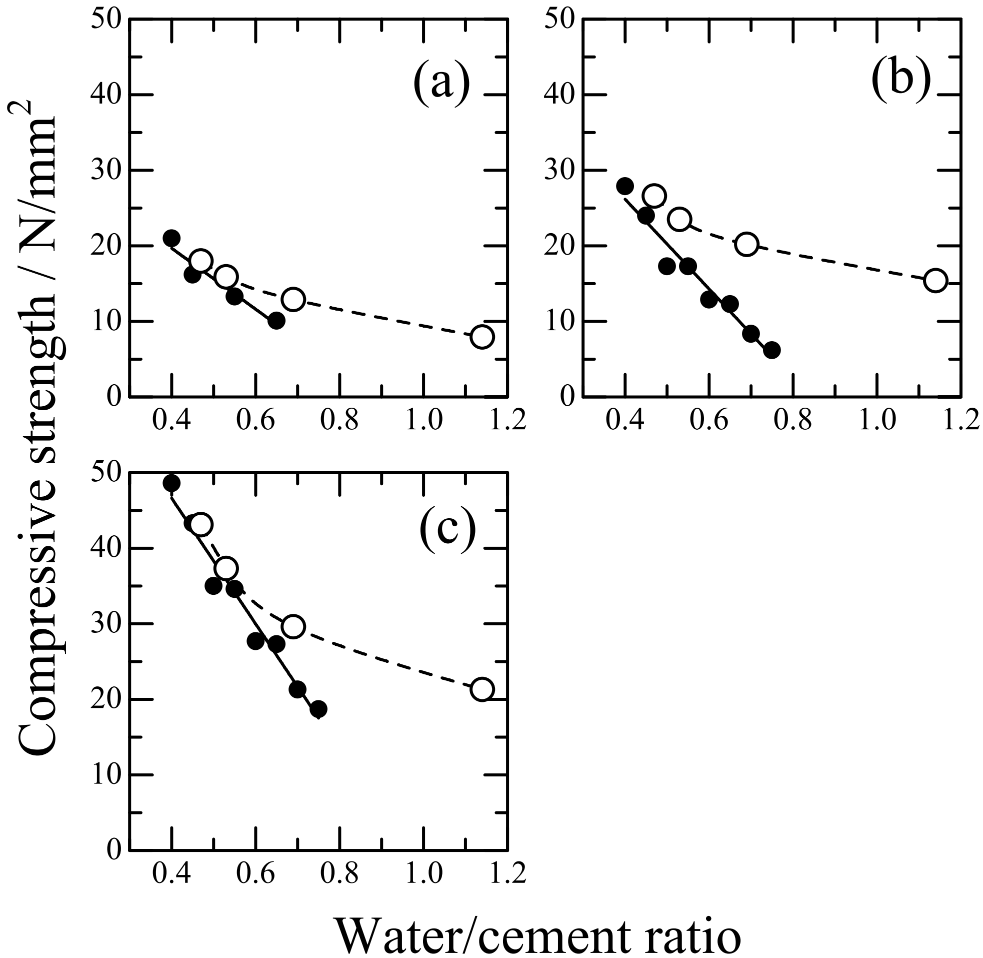

Figure 4. Effect of the ratio of water to cement on the compressive strength of the concrete products. ○; concrete materials with the sediments, ●; normal concrete products. Curing age; (a) 3, (b) 7, and (c) 28 days.

shrinkages were almost the same as those observed in the mass change test. Here, β is defined as the ratio of the total shrinkage of the concrete materials with the sediments to the total shrinkage of the normal concrete, similar to the α value. The β values were fairly similar to the α values. Generally, the water content has a significant influence on the mass loss and shrinkage. The conventional concrete mixtures are typically prepared with water/cement ratios of 0.4–0.7 (Al-Oraimi et al., 2006). Hence, it can be concluded that if the mix proportions of raw materials are optimized, with the ratio of water to cement less than 0.7 by weight, the tendencies of mass change and shrinkage in the materials with the sediments become almost similar to those obtained with normal concrete materials.

3.4 Compressive Strength

The concrete blocks were tested for compressive strength after 3, 7, 28 and 187 days of curing. The effects of the ratio of water to cement on the compressive strength of the concrete materials

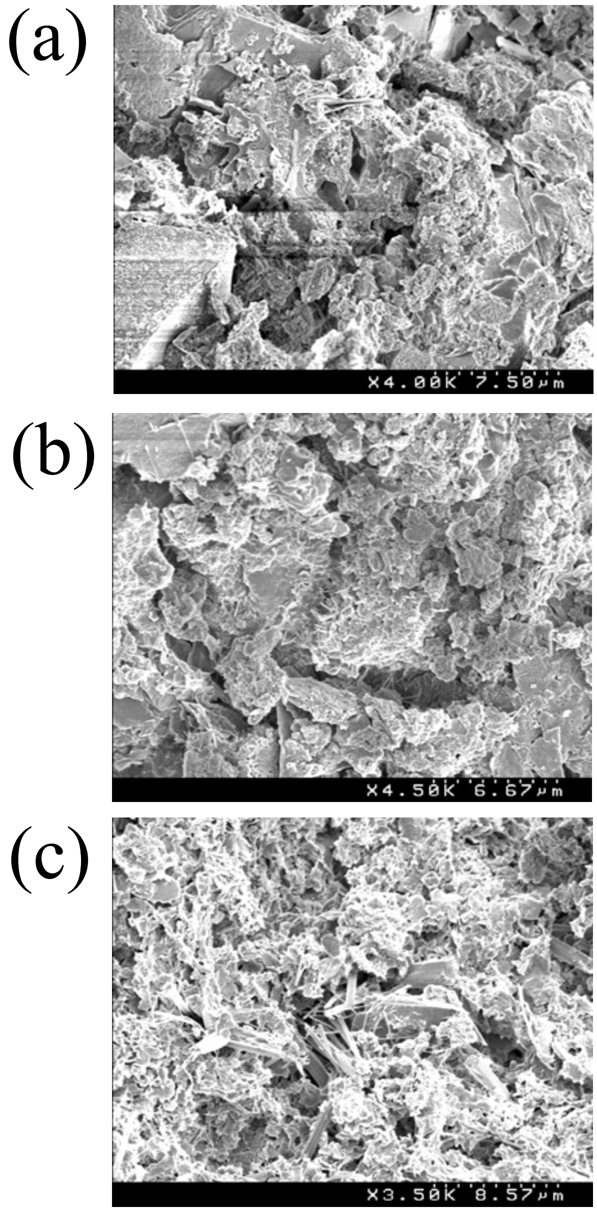

Figure 5. Scanning electron microscopic pictures of the microstructure of the sample surface with a curing age of 7 days. (a) Sample No.1, (b); No.2, and (c); No.5.

with sediments are illustrated in Fig. 4, which also shows the compressive strengths of the normal concrete products for comparison purposes. After a curing age of 3 to 28 days, the compressive strengths of the concrete materials with the sediments are better than those of the normal concrete blocks. This interesting phenomenon may be attributed to chlorides in the sediments, which did not prevent the solidification/stabilization processes such as the hydration reaction and ettringite formation before the pozzolanic reaction. The compressive strengths increased with the curing time until 28 days. With an increasing w/c ratio, the compressive strengths of the concrete products with the sediments decreased. The line slopes of compressive strengths for the concrete materials with the added sediments were smaller than those of normal concrete. These facts mean that when the sediments are used as raw materials the formation of concrete with a water/cement ratio of more than one is possible, while conventional concrete mixtures are typically prepared with a w/c ratio from 0.4 to 0.7. After 28 days of curing, the compressive strength was 43 MPa for the concrete products with w/c = 0.47 that used the sediments. After 187 days, the compressive strengths of the concrete blocks with the sediments were 44, 31 and 12 MPa with w/c = 0.47, 0.69 and 1.15, respectively.

3.5 Surface Morphology

To check the microstructure of the surface of the concrete products, the surface morphology was evaluated by scanning electron microscopy (SEM). The results are illustrated in Fig. 5. Ettringite ($3CaO{\cdot}Al_2O_3{\cdot}3CaSO_4{\cdot}32H_2O$) occurs in the concrete in various forms, often as spherical clusters of ettringite crystals, felt-like or parallel needles of different sizes (Ekolu et al., 2006; Marks and Dubberke, 1996; Midgley and Illston, 1985; Pei-wei et al., 2007; Sakai et al., 2004; Stark et al., 2000). If the ettringite crystallizes out without spatial obstruction, e.g. in pores, it has the typical needle-shaped crystal habit. The needle-shaped ettringite was observed only in Sample No. 5 with w/c = 1.15. The compressive strengths of the concrete products decreased with an increase in the w/c ratio. Therefore, we can conclude that the ettringite formed a three-dimensional network structure in the early stages of hydration (within 7 days) and the next solidification/stabilization processes occurred after the ettringite formation, with the pozzolanic reaction in the samples with a w/c of less than 0.69. Shrinkage cracks were observed in the surface of concrete product No. 5. This phenomenon could be attributed to significant mass loss and shrinkage on the basis of the data from Figs. 2 and 3. No shrinkage cracks occurred after 187 days of curing on the surface of the other samples.

3.6 Application in the field

We field-tested the concrete product with w/c = 0.47 made with sea bottom sediments for constructing marine reefs. First, a rectangular parallel shape (100 × 100 × 400 mm) of the concrete product was prepared and deployed in the sea after curing 187 days, as depicted in Fig. 6 (a). After approximately one year of deployment in the field, no damage was noticed as a result of the sea environmental changes. The observed compressive strengths were 48, 33 and 14 MPa for w/c ratios of 0.47, 0.69 and 1.15, respectively (Table 4). The change in the shrinkage might be attributed to the expansion due to the absorption of water. These results suggested that the concrete block contains sea bottom sediments has enough stability to be used for marine applications. Based on this encouraging data a scaled-up size of the concrete product (1700 × 1300 × 650 mm) to be used as a large marine reef was fabricated as shown in Fig. 7 (b). No steel

(a)

(b)

Figure 6. (a) Immersion of the concrete product in the sea. (b) Scaled-up size of concrete products for marine reefs.

Table 4. Comparison between shrinkage and compressive strength before and after deployment in the sea

No.	Before deployment [187 days of curing] (Sep. 20/2006)		After deployment (Aug. 28/2007)	
	Shrinkage (10^{-6} m/m)	Compressive strength (N/mm^2)	Shrinkage (10^{-6} m/m)	Compressive strength (N/mm^2)
1	635	51	248	60
2	680	44	215	48
4	718	31	100	33
5	3656	12	1646	14

reinforcement was added to the concrete. The application of the scaled-up size of the concrete product in the field is still being examined.

4. CONCLUSIONS

The use of sea sediments as a substitute for fine sand aggregate was investigated for the fabrication of concrete solids and marine reefs. The composition of the raw materials was optimized, and the different concrete materials were assessed by testing their slump, air content, mass change, total shrinkage and compressive strength. After 187 days of curing, the compressive strength was 44 MPa for the concrete products with w/c = 0.47 using the sediments. Furthermore, after immersing in the sea environment during approximately one year, the compressive strengths were 48, 33 and 14 MPa for the concretes with w/c = 0.47, 0.69 and 1.15, respectively. These results indicated that the concrete blocks with the sea bottom sediments which were continuously field-tested in the real sea environment for 1 year did not receive any damage from the sea.

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