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A CONCRETE HOME FOR MARINE MICRO INHABITANTS

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Abstract

In the last decades, the prevalence of artificial marine structures along natural shorelines has increased significantly. In some parts of the world, more than half of the available natural shoreline has been covered by these structures. Epibiotic diversity has been shown to decrease significantly on submerged artificial structures due to the reduced environmental heterogeneity of artificial environments. Natural rocky shores provide microhabitats through their rough surfaces, pits, rock pools and crevices. In contrast, modern building materials typically fail to provide many of these features. The ecological value of artificial coastal infrastructure could be increased through careful design of pre–fabricated ecological engineering units. Material selection is a crucial parameter in the design of these units. Reinforced concrete plays an important role in the design process due to its ease of production, relatively low cost and its suitability for mass construction.

To maximise the potential of concrete to support biodiversity and natural capital, binder composition, aggregate type, and texture are considered to be important parameters. To investigate these parameters, an experimental programme has been developed which is focusing on a number of different concrete designs. Key engineering parameters, such as strength, chloride diffusion coefficient, and their ecological colonisation performance are evaluated.

1. Introduction

In the last 40 years, the number of urban dwelling people has nearly doubled, with urbanized areas quadrupling in size [1]. Almost two thirds of the world's population is now estimated to live in coastal areas [2]. As the population has increased in coastal areas, more pressure has been put on coastal ecosystems through habitat conversion, increased pollution and more demand for marine resources [3]. These types of marine developments are always associated with fragmentation and loss of natural habitats, damaged seascapes and reduced biodiversity [4]. This irreversible alteration, often from natural to urban infrastructure development, is considered to be one of the main threats to coastal ecosystem and sustainability [5]. Natural habitats provide microhabitats through their rough surfaces, pits, rock pools and crevices. In contrast, modern building materials typically fail to provide many of these features, with a notable impact on the organisms that would seek to colonise these surfaces. Artificial marine structures could support more invasive non-indigenous species and less diverse communities than natural habitats [5, 6]. The ecological value of artificial coastal infrastructure could be increased through careful design of pre–fabricated ecological engineering units. Material selection is a crucial parameter in the design of these units. Reinforced concrete plays an important role in the design process due to its ease of production, relatively low cost and its suitability for mass construction. Concrete composition plays a significant role in biodiversity enhancement of marine structures [7]. More than half of marine infrastructures are made using Portland cement concrete, and this has been shown to provide a good support for colonising organisms as calcareous skeletons deposit calcium carbonate onto the surface in the biogenic build-up process [8]. Concrete, however, has a high surface alkalinity (pH 12-13 compared to 8 for seawater), and this could reduce settlement of marine organisms and result in communities dominated by a few alkotolerant taxa such as barnacles [9]. The addition of pozzolanic materials such as GGBS to the concrete mix could reduce the alkalinity of the concrete and create more suitable surfaces for colonisation by marine species [10]. As chloride ingress in reinforced concrete structures in marine environments is one of the most challenging forms of degradation, replacement of Portland cement by pozzolanic materials such as GGBS could improve concrete durability and delay the reinforcement corrosion [11]. Chloride ions exist in seawater and can destroy the passive layer at the rebar surface when the chloride concentration at the cover depth is greater than the critical chloride concentration (C_{cr}). Previous research [12,13] has shown that as the GGBS content increases, the possibility of steel corrosion decreases. Other factors such as surface texture, holes, crack pits and pools have been also investigated and are found to have a significant and direct effect on increasing biodiversity on artificial marine infrastructures [14].

Although some research has been conducted to use concrete as a new habitat for marine micro habitants, they rarely consider the engineering side and focus mainly on ecological issues. Here, the alternative possibility of using coastal infrastructures as a habitat for epibiota is exploring. The service life that may be expected from these different mix designs is also examined and show how they are being assessed in the field.

2. Materials and Methods

A number of concrete mixes were designed with a view to assessing their engineering performance, as well as their ability to support marine life. A number of specimens were cast for each mix, including:

- 8 reinforced concrete tiles of dimension 200 x 200 x 40 mm which would be installed in a marine environment;
- 3 concrete cylinders of diameter 100mm and height 200mm for assessing resistance to chloride ingress;
- 6 concrete cubes of dimension 100mm to confirm concrete strength at 7 and 28 days.

As the concrete tiles would be subject to corrosion arising from sea-borne chlorides, the exposure class was considered to be XS3. This also corresponds to the tidal zone, as the samples will not be fully submerged, and subjected to spray and inter-tidal conditions. For this particular exposure class, the Irish National Annex to EN206 requires a minimum cement content of 360 kg/m^3, a maximum water/binder ratio of 0.5 and a minimum strength class of C35/45.Nine different concrete compositions were designed in this study, and parameters of interest were binder type, aggregate type and influence of plasticiser. Two binder compositions were used: 100% CEM I, and a 50% blend of CEM I and GGBS. This was selected as it was considered that it would provide a higher chloride resistance, as well as a significant change in concrete alkalinity that could influence marine colonisation. Plasticiser was also added as a variable and the selected dosage was 0.8% of cement content. It is not expected to have any major influence on the engineering performance, but its influence on colonisation behaviour is completely unknown. Finally, the coarse aggregates chosen were limestone and granite. Limestone is the dominant aggregate type in Ireland and significant quantities of concrete are manufactured using this. Granite was also chosen, as anecdotal experience has shown that marine organisms are often attracted to materials with the reddish colour of coralline algae. As such, the granite colouring is of interest to us and will be used as a variable for the field testing. A final mix (mix 9) was added to the testing programme as an initial assessment of the influence of concrete texture, whereby a rough surface was obtained by removing the concrete surface as the material was setting. A full list of the selected mixes is described in Tab. 1.

Table 1: Concrete mix design compositions.

Mix	Binder	Aggregate	Reinforcement	Plasticiser
1	CEM I	Limestone	Steel mesh	No
2	CEM I	Limestone	Steel mesh	Yes
3	CEM I + GGBS	Limestone	Steel mesh	No
4	CEM I + GGBS	Limestone	Steel mesh	Yes
5	CEM I	Granite	Steel mesh	No
6	CEM I	Granite	Steel mesh	Yes
7	CEM I + GGBS	Granite	Steel mesh	No
8	CEM I + GGBS	Granite	Steel mesh	Yes
9	CEM I	Limestone	Steel mesh	Yes

2.1 Concrete Characterisation

Compressive strength of the concrete cubes was obtained by testing according to EN 12390-3 [15]. The chloride resistance was determined by use of a chloride migration test, and the particular method used was the non-steady state migration test according to NordTest NT BUILD 492 [16]. The test involves driving chloride ions through a concrete section of 100mm diameter and 50mm thickness under the action of the electric field. The catholyte solution is 10% NaCl by mass in tap water and anolyte solution is 0.3M NaOH in distilled water. A voltage, typically of the order of 30 V is applied for 24 hours, after which the concrete sample is removed and split. The depth of chloride penetration is visually determined by spraying 0.1 M silver nitrate solution on the freshly split concrete section. To determine the chloride concentration at the depth, X, for a service life of t=50 years, Cranks solution to Ficks Law was used:

$$C(x,t) = C_{sn}\left[1 - \operatorname{erf}\left(\frac{X}{2\sqrt{D_m t}}\right)\right] \tag{1}$$

where C_{sn} is surface chloride concentration and D_m is the mean chloride diffusion coefficient for the exposure time t and calculated from Eq. 2 and 3.

$$D_m(t) = \frac{1}{t}\int_0^t D(\tau).d\tau \tag{2}$$

$$D(\tau) = D_R(\frac{t_R}{t})^m \tag{3}$$

For this study, the surface chloride concentration was taken as 0.8% by mass of binder. This is based on research by Poulsen and Sørensen [17] who assessed 34 year old concrete bridges in a marine environment. It is recognised that this is a time and material dependent parameter, but the use of a fixed value is considered appropriate for comparative purposes. The parameter m is an age factor, and based on the work of Attari et al. [18] is taken as 0.17 for 100% OPC binders and 0.3 for binders containing 50% GGBS, t_R is reference time (in this case 81 days). Determination of effective diffusion coefficients from migration testing is as described by Tang and Nilsson [19].

3. Results and Discussion

3.1 Compression test

The results of the compression testing are presented in Tab. 2. It can be seen that the use of a 50% GGBS replacement level resulted in almost no change to the strength. The most significant change was in the early strength of the concrete samples manufactured using granite aggregate, but this appears to be reduced at 28 days. All samples comfortable achieve the minimum strength of exposure class XS3 (C35/45).

Table 2: Concrete compressive strength results

Mix	Average 7 days compressive strength (MPa)	Average 28 days compressive strength (MPa)
1	41.30	50.24
2	40.78	45.13
3	35.79	50.12
4	31.72	49.94
5	34.78	47.46
6	32.93	41.92
7	26.32	47.42
8	26.40	45.74

3.2 Chloride Migration

Results of the chloride migration testing are shown in Tab. 3. The required service life was 50 years, and as such the data was manipulated using equations 1, 2 and 3 so as to produce the time dependent diffusion coefficient for this period. This is then used to determine the chloride content at a selected concrete cover depth of 50mm. Corrosion is typically accepted to be initiated when the chloride concentration reaches a critical value of 0.4% by mass of binder.

In all cases it can be seen that the critical variable is the use of GGBS; without this, the required service life of 50 years cannot be achieved. This is supported by other research in this area [20]. The influence of the other parameters (plasticiser, aggregate) is found to be much lower, and these can be utilised without compromising performance of the concrete.

Table 3: Results of chloride resistance tests

Mix	**D_{nssm} (x10^{-12} m^2/s)**	**D_R (x$10^{-12}$$m^2/s$)**	**D_m (x$10^{-12}$$m^2/s$)**	**C(5,50)**
1	17.08	13.00	3.66	0.51
2	21.46	16.61	4.67	0.54
3	3.52	2.39	0.44	0.14
4	3.34	2.25	0.41	0.13
5	17.40	13.26	3.73	0.52
6	18.05	13.75	3.87	0.52
7	3.00	1.96	0.36	0.11
8	3.13	2.06	0.38	0.12

The next strand in this work is the ecological assessment of the concrete mixes, and the 200mm concrete tiles were deployed on a breakwater on Ireland's east coast in April 2018 (Fig.1). Samples are attached to the exposed and sheltered surfaces on this rocky breakwater and are fully submerged during high tide. They will remain in this intertidal environment for 12 months to evaluate the influence of concrete mix design on colonisation behaviour. Quadrat sampling will determine if different concrete mixes can lead to improved substrates for marine life. This strand of the work will be reported at a later stage.

Figure 1: Concrete tiles installation and deployment

4. Conclusions

Corrosion of reinforced concrete is the main threat to marine structures. The results of our service life prediction showed that the addition of GGBS plays a significant role in achieving the required service life and that if this is included then other parameters can be included without issue. Concrete mixes with limestone aggregate were also shown to be slightly stronger than mixes with granite aggregate. The connection between these engineering parameters and the marine colonisation behaviour will be monitored with interest over the next 12 months.

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