Ecostructure: Concrete design for improved marine biodiversity

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ABSTRACT: In some parts of the world artificial marine structures now cover more than half of the available natural shoreline. Due to the impact of climate change and the need for improved coastal defences this number is set to increase, and these will inevitably have a significant impact on the local marine ecosystem. As an indicator of this impact, research in the UK has shown the epibiotic diversity to be significantly reduced on submerged artificial structures.
The Ecostructure project is part funded by the Ireland Wales Cooperation Programme and has the objective of addressing climate change adaptation through ecologically sensitive coastal infrastructure. The approach under development is to increase the ecological value of artificial coastal infrastructure in the Irish Sea through careful design of pre–fabricated ecological engineering units.
A key parameter in the design of these units is material selection. Reinforced concrete plays an important role in the design of these units, due to its ease of production, relatively low cost and its suitability for mass construction. However when assessing concrete mixes for use in this application, a key issue is how easily the local marine organisms can colonise the hard concrete substrate. It is considered that key parameters can include binder composition, aggregate type, texture, colour etc. To assess these parameters, a testing programme has been developed that is focusing on 9 different concrete designs. These are assessed for key engineering parameters (strength, chloride diffusion coefficient etc.), as well their ecological colonisation performance. This is determined by placing concrete samples in marine environments in Ireland and measuring the ecological diversity through quadrat sampling at a number of time intervals. This testing is taking place in Dublin and initial results are presented.

KEY WORDS: Ecological engineering, Coastal defences, Biodiversity, Habitat enhancement, Concrete design

1 INTRODUCTION

Human kind has always lived close to the coast. Costal habitats provide precious resources for the harvesting of food, assimilation of waste and secure anchorage for shipping [1, 2].

Statistics from the United Nations Environmental Programme UNEP2016 [3] predict that over the next 50-100 years the population distribution will change so that between 50-70% of people will be living in coastal areas. Globally, coastal margins are experiencing a significant increase in population and associated construction of artificial structures. Data from the CORINE project (Coordination of information on the environment) showed that 22,000 km^2 of Europe's coastal zones are covered in concrete or asphalt [4], and that between 1990 and 2000 artificial marine structures increased by almost 1900 km^2 [5]. This irreversible alteration, often from natural to urban infrastructure development, is considered one of the main threats to coastal system integrity and sustainability [2].

Rocky reefs, which provide primary habitats for a significant number of subtidal animals and plants, continue to be destroyed and replaced with artificial structures [6]. Despite this alteration, there remains little understanding of the role of urban infrastructures as marine habitats, and the ecological relationship of man-made habitats and adjacent natural habitats [7] remains unclear. However, subtidal assemblages are found living on artificial marine structures such as concrete walls, fibreglass pontoons and wooden pilings; these have been shown to be function as simplified surrogates for natural rocky reefs [7, 8]. Artificial marine structures could support more invasive non- indigenous species and less diverse communities than natural habitats [9, 10]. In addition to providing significant habitat for epibiota, these artificial marine infrastructures provide substantial refuge habitats for mobile species during high water, while during low water, a wide range of birds can be observed feeding on and around the structures [11, 12].

As the increasing impact of global climate change continues to be felt, the intensity of storms and the height of sea levels are predicted to increase; this introduces an inevitable need for enhanced coastal defence structures. Furthermore, the role of artificial structures as appropriate habitats for non-native species is important if we are to understand the patterns of biological invasion in marine areas [13].

Research by Glasby and Connell [7] has showed that age and composition of structures have a profound effect on the identity and abundances of epibiotic organisms within a habitat, and that these factors differ significantly between rocky reef and artificial structures. Ecological engineering tries to bring together engineering practices and ecological understanding to build structures which will benefit marine life, while also meeting society's requirements [14]. The ecological value of artificial structures has been enhanced by increasing their potential to support biodiversity. Researchers have investigated ways of testing different engineering factors to enhance topographical complexity at different scales and to enhance the habitats that are mostly absent from artificial structures [15]. Surface texture, holes, cracks, pits and pools have been proven to have a significant effect on increasing biodiversity on artificial marine infrastructures [16, 17, 18, 19, 20]. Increasing surface complexity is known to encourage biological development [21, 22]. Perkol-Finkel and Sella [22] compared the smooth and textured surfaces and found that colonization is almost 10% more on a textured surface than a smooth surface.

Construction materials also play a significant role in biodiversity enhancement. Reinforced concrete could be the most effective and feasible material due to its ease of production, relatively low cost, surface topographies and suitability for mass construction [23]. Concrete has high surface alkalinity (pH 12-13 compared to 8 for seawater), which could impair settlement of marine organisms. This could however result in communities dominated by a few alkotolerant taxa such as barnacles [24] and the establishment of different communities on concrete marine structures than what is observed on natural habitats. Portland cement has shown to be a good support for colonising organisms with calcareous skeletons like oysters, serpulid worms, barnacles and corals deposit calcium carbonate onto the surface in the biogenic build-up process [25]. The environmental footprint of concrete and its associated CO_2 emission concerns could also be reduced by replacing Portland cement with pozzolanic industry by-products such as ground granulated blast-furnace slag (GGBS), fly-ash and silica fume. Adding pozzolans to the concrete mix could also reduce the alkalinity of the of concretes [26, 27] and create more suitable surfaces for colonisation by marine species [28]. The use of pozzolanic materials such as GGBS has also been shown to improve concrete durability in marine environments and delay the onset of reinforcement corrosion [29, 30, 31]. Chloride ions exist in seawater and can destroy the passive layer at the rebar surface of reinforced concrete when the chloride concentration at rebar level reaches a critical threshold level. Previous research [32, 33, 34, 35] has shown that by replacing a portion of the Portland cement with GGBS, the expected service life can be increased.

Some researchers [23, 36] have tried to replace the aggregate with waste materials such as shells or ceramic in order to provide a more textured surfaces and encourage marine life settlement. Although waste materials have relatively low cost, they usually do not have engineering requirement to replace the aggregate in the concrete mix design.

This paper describes collaboration between ecologists and engineers to develop a materials-based approach for providing a habitat to marine species in the west part of Irish Sea. Reinforced concrete tiles were cast and placed in Mornington, Ireland. The aim of this project is to investigate the effect of modifying the concrete composition and surface texture on the concretes capability to support marine life. The size of the tiles utilised was constrained by engineering consideration and cost, but the overall objective was to test a design that could be generally appropriate to a wide range of conditions.

2 MATERIALS AND METHODS

Nine different concrete mixes were trialled in this study, and a brief overview is provided in Table 1.

Table 1. Mix design and details.

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

The control binder used for this work was a CEM I Portland cement and was used for all cast reinforced concrete tiles in this project. As the concrete tiles would be subject to corrosion arising from sea-borne chlorides, the appropriate exposure class was XS3. This also corresponds to the tidal zone, as the samples will not be fully submerged. For this particular exposure class, the National Annex to EN206 requires a minimum cement content of 360 kg/m^3, a maximum water/binder ratio of 0.50 and a minimum strength class of C35/45. Of the 9 mixes tested, 4 were designed using a GGBS replacement level of 50%. This would increase the chloride resistance of the concrete while also changing the alkalinity of the concrete, potentially making them more hospitable to marine life. A series of tiles were also built with a rough surface to provide some initial feedback on the effect of texture, by comparing the results from the same mix design with a standard vibrated surface finish. The texture was formed using a wire brush to expose the aggregate some 2 hours after casting the concrete.

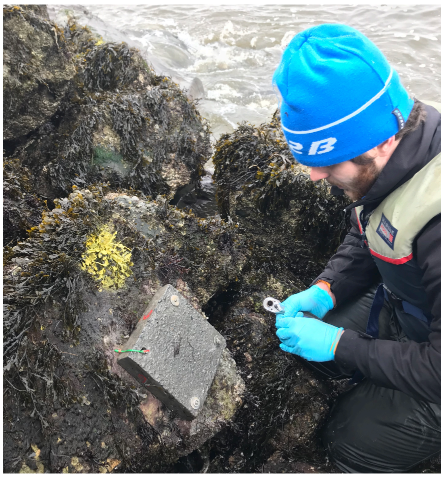
Limestone and granite were chosen as suitable aggregates to fulfil the engineering concrete mix requirements. The proportion of fine aggregate to coarse aggregate was 0.4 in all mixes. Plasticisers were also added to 4 mixes at the ratio of 0.8% of cement content.

For each designed mix, 8 reinforced concrete tiles of dimension 200 x 200 x 40 mm were manufactured, leading to a total of 72 samples. Reinforcement mesh was placed in the middle of tiles and samples were cast with 4 holes of 10 mm diameter located in the corners of each slab to facilitate installation of the tiles. The casting process can be seen in Figure 1. All specimens were cured in the a water bath at a temperature of 20°C for 28 days to ensure a consistent level of curing.

6 no. 100mm cube samples were made for compression testing at 7 and 28 days for each mix. The compressive strength obtained for these tiles was found to be 45-50 MPa after 28 days curing in water, confirming that the mix was compatible with XS3 exposure class. To investigate the chloride penetration resistance, 3 cylinders of diameter 100 and height 200 mm were also cast for each mix design.

Figure 1. Tiles mould and casting

The concrete tiles were deployed on the breakwater at Mornington, on Ireland’s east coast (Figure 2). They were attached to exposed and sheltered surfaces on the rocky breakwater at Mornington in April 2018. These habitats were submerged during high tide. They will remain in the intertidal environment for 12 months to evaluate their performance with respect to supporting marine biodiversity. Over the next 12 months, we will be working with our ecologist colleagues to monitor colonisation of the concrete tiles in an effort to evaluate whether some of the concretes provide a better substrate for marine life than others. The project will examine the impact of concrete composition and complexity on biological performance through periodic quadrat sampling. This visual inspection will allow us to draw preliminary conclusions on the impact of material selection on ecological behaviour.



a.

b.

Figure 2. Tiles (a) installation and (b) deployment

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