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Hydrolink

GREENING FOR IMPROVING THE RESILIENCE OF GREY INFRASTRUCTURE ASSETS

BY YUICHIRO KAWABATA & LARISSA A. NAYLOR

Coastal, estuarine and marine environments (hereafter, marine environments) are harsh for grey infrastructure, especially concrete and mortar-joint based infrastructure assets like seawalls, bridges, ports and harbours. Chloride-induced corrosion of reinforced concrete structures is one of the most severe asset deterioration problems, which leads to loss of structural capacity of the asset. This is caused by repeated exposure to intense marine environmental conditions that negatively affect the durability and maintenance of concrete engineering structures. These effects are found worldwide, are very expensive to manage and are expected to increase as our climate continues to change [1].

As such, extensive efforts have been paid by grey engineers to understand and manage these risks of deterioration. Deteriorated structures also require burdensome repair process including erection of temporary scaffolds, removal of deteriorated concrete, restoration of removed cross-section and application of cathodic protection in some cases. These offshore works are frequently impeded by tidal conditions and wave action. Therefore, highly-durable materials such as anti-corrosive steel, highly-durable concrete using chemical and/or mineral admixtures, and coatings are typically recommended, although these traditional approaches to reduce the risk of asset deterioration are expensive. Moreover, experimental studies comparing the ability of different admixtures and coatings on improving the durability of concrete from chloride ion penetration [2] have shown that these additives lose their effectiveness in zones XS2 (intertidal) and XS3 (supratidal) within 10 years of deployment in the harsh intertidal conditions. Therefore, there is a pressing need to identify alternative methods of improving the durability of marine concrete to harsh environmental conditions.

Bioprotection to improve the resilience of grey infrastructure assets

In the past decade, engineering and biogeomorphology researchers in Japan, Italy and the United Kingdom have explored the possibility of

Figure 1. Barnacles on concrete superstructure of open-type pier

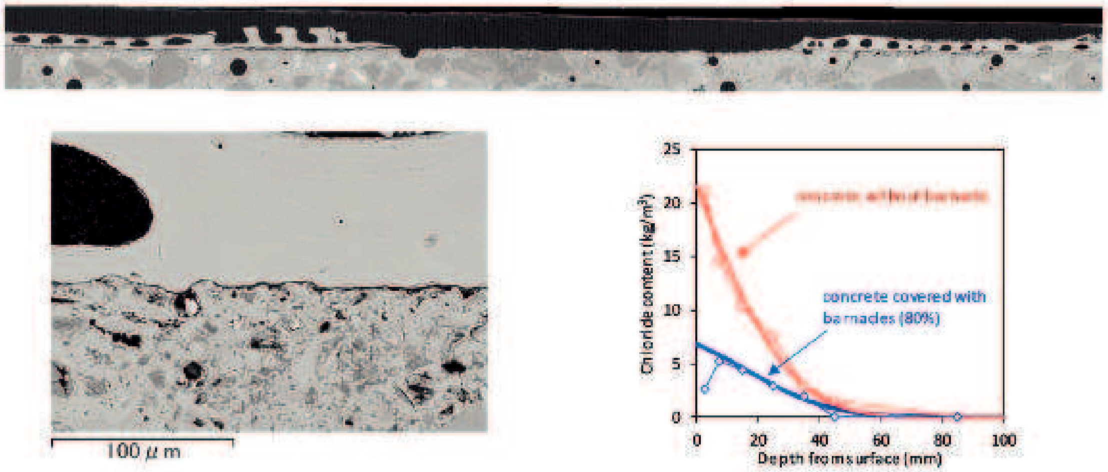


Figure 2. Basal membrane of barnacles attached on concrete surface and chloride ion profile in concrete. Top shows basal membrane of barnacles attached on concrete surface and bottomkawak left is interface between concrete and basal membrane. Bottom right is chloride ion profile in concretes w/ and w/o barnacles exposed to marine tidal zone for approximately 10 years, showing significant prevention of barnacles against chloride ion penetration

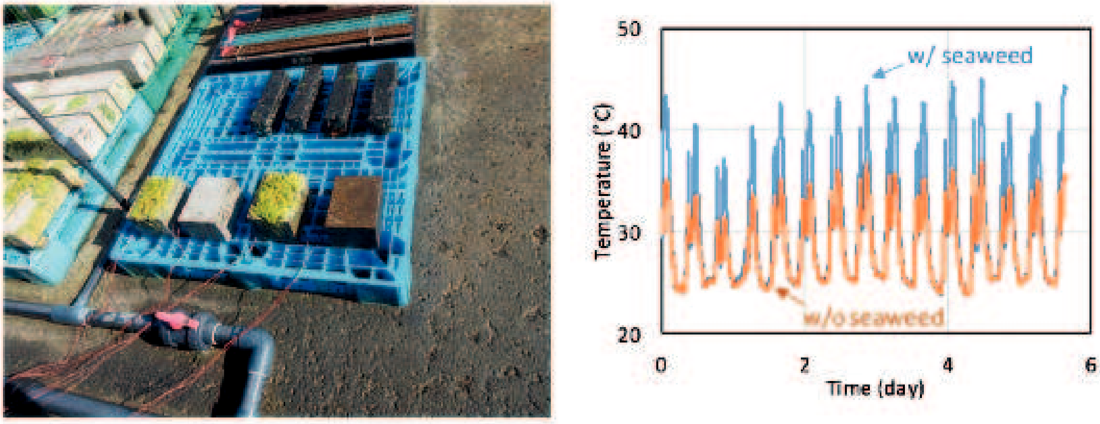


Figure 3. Influence of seaweed on temperature variation (measurement: the end of July 2019)

(a) Field-exposure test with and without seaweed on concrete surfacesurface

(b) Temperature of concrete (5mm from the surface)

using ecology to help reduce the risk and/or impacts of weathering-related deterioration of marine concrete and rock materials [3-7]; this is known as bioprotection. Other researchers have also explored the effects of cyanobacteria and algae on the durability of marine concrete [8]. Recent studies interestingly conclude that bioprotective species appear to enhance the durability of assets [3]. One example is barnacles – a species which is commonly found on hard marine engineering structures worldwide. Barnacles are frequently found colonizing concrete surfaces in the intertidal (XS2) zone (Figure 1). Figure 2 shows the interface between concrete and basal membrane of barnacles. The basal membrane of many barnacle species is significantly denser than concrete, and adheres very well to concrete. Also, even when the barnacles are detached from the concrete surface, they produce a secondary cement secretion, which is denser than concrete. Consequently, the basal membrane and secondary-cementing substances play a role as an inorganic surface coating. The previous study revealed that the basal membrane of a barnacle has a potential to prohibit chloride ion from penetration [4]. The possibility of durability enhancement with marine growth raises the next question: how long can this enhancement be maintained? The life span of grey infrastructure is generally 50-100 years whilst that of marine organisms is 1-10 years, with species like barnacles reproducing and settling on marine infrastructure annually. Therefore, it is questioned whether bioproctetive species like barnacles can influence the long-term durability of marine concrete structures. In order to answer this question, the Port and Airport Research Institute, Japan, conducted a field-exposure test of a large-scale reinforced concrete beam (200 × 300 × 2400 mm) for approximately 10 years. Following exposure, concrete cores were sampled from the beam and the profile of chloride ions in the concrete was measured. Figure 2 shows distinct reduction in chloride ion penetration into concrete covered with barnacles (blue plots), suggesting that the beneficial effect of barnacles is maintained for at least 10 years. Also, the rapid electrical migration test on concrete cores of real field structure and scanning electron microscopy image analysis of the barnacle-concrete interface, all supported this result [9].

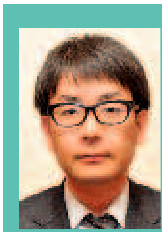
Seaweed and other algae (also often referred to as fouling organisms of marine infrastructure) have an ability to regulate microclimatic variability, such as temperature and humidity fluxes. In the intertidal zone, the temperature of concrete surfaces can increase to over 50 °C due to ambient temperature and solar radiation during the low tide phase and decreases by 10-20 °C due to seawater supply during high tide [10]. Such temperature variability may accelerate mechanical weathering and induce micro-cracking of concrete surface, which reduces the resistance of concrete against mass transfer and strength [11,12]. Coombes et al., via an exposure experiment at three sites in South West England, UK, reported a statistically significant, positive effect of microclimatic buffering by seaweed, where the variability of temperature and humidity was significantly reduced [8]. This effect was confirmed in Japan as shown in Figure 3, where seaweed growth reduces the temperature of concrete surface by approximately 15 °C. Barnacles were also found to play a similar role in regulating temperature variability of marine concrete and rocks (limestone and granite) in laboratory trials [5]. Cyclic thermal history is known to induce micro-cracks on concrete surface [10, 11]; a stable microclimate is thus beneficial for concrete durability.

There is also some evidence worldwide showing that deterioration of grey marine concrete infrastructure can also be caused by biology, where algae (mainly caused by organic acids), found within the concrete mix, or growing on the surface of marine concrete and rocks, can cause deterioration at the micron/mineral scale [13]. Therefore, recent research shows that some biology can have positive benefits for asset resilience (as well as negative effects); these potential benefits and/or risks should be considered in the design and construction of green-grey and traditional engineering structures [14].

Enhancing the design of concrete engineering structures to encourage bioprotective species

Recent research has also demonstrated that ecological growth on marine concrete structures can be improved by changing surface texture of traditionally smooth grey assets [15-17]. Altering the texture of marine concrete can occur at a range of spatial scales from mm-scale for target early-coloniser species such as barnacles (e.g. [15]), to creating pits and crevices suitable for mobile species (e.g. [18]). Creating simple and inexpensive textures at the mm-scale has been shown to statistically increase the rate of barnacle settlement in the UK [15, 19] and higher covers of barnacles were found to reduce thermal fluxes on marine concrete (and limestone and granites used in coastal engineering assets) [5], thus reducing the risk of thermal-related deterioration. This means that it is simple and inexpensive to alter the surface texture of marine concrete to improve the rate at which barnacles settle – which when coupled with the reduced chloride ingress and improved microclimate regulation discussed earlier, has the potential to increase the bioprotective ability of barnacles by achieving fuller cover of concrete surfaces, more quickly. Recent research, from the largest known experimental concrete tile experiment in the UK, has shown that designing surface textures from the mm to dm scale will have the best ecological outcomes in northern latitudes. It is thus recommended that designs are created to optimize for bioprotective as well as wider ecological benefits that a more structurally heterogeneous surface marine concrete design provides; this will better mimic the natural geomorphic diversity on rocky shores.

In addition to manipulating the surface texture, the chemical composition of marine concrete can also be altered to improve ecological suitability. For example, in Japan, "Environmentally Active Concrete (EAC)" was developed by adding amino acid to concrete, which chemically promotes the growth of algae significantly by releasing amino acid from the concrete [20]. EAC was implemented in the Port of Wajima and this project was awarded a "Working with Nature" Prize by PIANC in 2018 [21]. Such approaches are quite beneficial to enhance not only the ecological value of coastal and marine engineering assets to 'green the grey' [14], but can also potentially improve the durability of grey marine infrastructure.



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Concluding remarks

This article discusses the possibility of enhanced resilience of grey infrastructure assets by greening the grey. Although further work is still necessary, especially engineering-scale field trials combining material composition, material texture and the effects on both ecological (i.e. greening) value and marine infrastructure durability and resilience (i.e. grey), the results to date seem promising that green-grey infrastructure has the potential to build a win-win relationship for both ecosystems and society. ■

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