Glass Fibre Reinforcement - Durability and Structural Design

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Abstract: Reinforced concrete is a composite material with tensile strength enhanced by reinforcement. An avoidance strategy for the corrosion to reinforcement induced by chloride attack and carbonation, is the use of glass fibre reinforcement. This material is achieving rapid take-up in Australia in maritime facilities. A desktop risk assessment suggests the durability of GFRP material is influenced by chemical and thermal deterioration mechanisms of the epoxy or vinyl ester binder indicating the need for quality assured polymers meeting Tg ≥ 100 °C. The properties of several different bar types now available in Australia are illustrated indicating a unique design required on a product-by-product basis. Some key features of the differences between carbon steel reinforcement design and GFRP bar design are explained with reference to the available international standards. Work constructed and in progress designed by ATC include jetties, wharves, dolphins, crash barriers, precast walls, slab on grade and balconies in marine exposure zones.

Keywords: Fibre reinforced polymer (FRP), Glass FRP (GFRP), reinforcement, durability, marine, corrosion, concrete, design

1. Introduction

1.1. Challenges to Durability of Marine Environs

The Concrete Institute's treatise on performance concretes for marine environs states “In Australia, steel corrosion is considered to be the main cause of deterioration of reinforced concrete exposed to marine conditions” (1). Structural strategies for durability include design of the shape of the member for the additional impacts and cracking that may ensue due to events during service, in addition to limiting original cracks with potential to admit sea water (4).

To increase design lives in B1-C2 marine exposure zones from 25 years to 50-100 years, material durability strategies may include: increasing the cover of the concrete (4-7); reducing the porosity of the concrete by increasing the grade (4-7); reducing porosity and increasing water repellency by use of admixtures; specification of mix designs of performance concretes (1, 6, 7); in addition to crack (width) control by design and admixture.

Performance concretes limit the shrinkage, capillary suction and diffusion of seawater into concrete and generally offer improved matrix chloride and sulfate resistance (1, 6, 7) as measured by durability tests (refs 1,3,5-7) that are not specified in AS 3600 (5). Crack control by design, admixture and repair is necessary[1]. Durability proposals may include cathodic prevention solutions such as impressed current protection introduced into the new build (12). Planning for future maintenance includes concrete repair, sacrificial anodes and/or cathodic protection (12). Other post-construction strategies include barriers such as coatings and impregnations, pile jackets (12). The costs of these strategies are variable and add to the base price of concrete estimated in Table 1 overleaf.

Fibre Reinforced Polymer (FRP) reinforcing bars and strands are made from filaments or fibres of glass held in a polymeric resin matrix binder (or glue), epoxy or vinyl ester by a process known as pultrusion. The focus of this article is glass FRP (GFRP) for structural concrete. Such composites are electrical, thermal and magnetic insulators, and do not corrode in the same manner as steel in chloride-contaminated or carbonated concrete and can offer an alternative to steel reinforcement known as an “avoidance” strategy.

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[1] Crack repair is not necessarily recommended during defects liability due to movement at this phase.

Table 1. Select strategies and cost escalation of achieving design lives in Concrete Maritime Structures

Durability Method:	Reduce porosity by increasing strength only[a]			Performance Admixture[b]	Performance Concretes[c]		Cathodic prevention[d]	Maintenance and Life Extension[d]	
	N32 (steel reinforced)	Upgrade to N40	Upgrade to N50	Added to N40	TfNSW IC-QA- B80 S40 B2	TfNSW IC-QA-B80 S50-60 C	Impressed Current	Concrete Repair	Cathodic Protection /m^2
Location	$AU\$/m^3$	$AU\$/m^3$	$AU\$/m^3$	$AU\$/m^3$	$AU\$/m^3$	$AU\$/m^3$	$AU\$/m^2$	$AU\$/m^2$	$AU\$/m^2$
Perth	$263	+$8.60	+$37.70	+$65-$85	-	-	$160-$200	$1,600 - $3,500	$1000 - $1500
Sydney	$325	+$29.10	+$50.60	+$65-$85	c	c			

a: Suspended slab 150-300 mm thick including delivery, placing, wastage and loss not including special pumping sampling and testing (4).

b: Performance enhancements include reduced porosity, capillary suction and/or crack reduction. To fully eliminate capillary suction and waterproof the member $150/$m^2$ (Perth), $100/$m^3$ (Sydney) inclusive.

c: Pre-approved performance concretes are available in NSW (ref 7) and form an important role in maritime structures (pricing not available at time of writing). Such concretes are not available in WA which relies upon Standards or Performance Specification (ref 1).

d: Industry contractor estimates, maritime works only.

1.2 Prototypes and Scale of Adoption

Although GFRP has been used in Japan and Europe (11) Australian adoption of GFRP is primarily from Canadian experience and technology. In Canada, de-icing salts tracked onto bridge decks by vehicles lead to short design lives and serviceability issues maintaining the busy concrete bridge decks. GFRP was installed in four bridges in the US and Canada and the results published in 2004 (19) (which are supported by concrete beneath and therefore only experience "one way" flexural loads). It is understood that the number of bridges in which GFRP is installed in the US now stands at 22 (29).Two design standards emerged from this research, the CSA S6-06 Canadian Highway Bridge Design Code (8b), and American Association of State Highway and Transportation officials (AASHTO) (13 b) published by Florida Department of Transport.

In 2011 Airey Taylor Consulting (ATC) sponsored research at the University of Western Australia (UWA) into an alternative member type (load bearing columns), the findings regarding failure mode informing design for column members primarily experiencing compression in corrosive environments (20-21). This led to the first protoype in Western Australia designed by a consultancy completed in 2014, the Majestic Pier Walkway, replacing a galvanised structure rusted after 20 years exposure on a peninsula into the Swan River, Perth (22); followed by use the inlet diaphragm walls at Elizabeth Quay, completed in 2016 (24). In 2020 further Academic Research following the initial industry-academic partnership ensued, on the axial, eccentric and flexural loads of circular column research (23).

In excess of 70 major projects, the majority maritime, have ensued across Australia 2014-present, with GFRP's durability, thermal and magnetic insulation qualities also favouring use in light rail projects of the major centres, defence and radio-isotope facilities (29). Noteworthy maritime constructions include the Sydney Wharves redevelopment. It is our understanding however that in jetties, the primary adoption by others has been in the decks, not the pylons (24, 26, 29). The product has been trialed (25) and constructed (26) with concrete alternatives (geopolymers).

Canadian applications have extended into car parks. At La Chancelière car park a side by side trial is underway trialing GFRP *vs.* traditional carbon steel and the durability of “two way” flexural loads experienced by suspended slabs which compare with “one way” loads of concrete supported bridge decks (27).

Canadian-Australian collaborations since 2011 involve the University of Sherbrooke, UWA, University of Melbourne and University of South Queensland and others demonstrating GFRP effectiveness in bending, shear, compression and impact. The adoption of GFRP in Australia continues to be led through innovative prototype design assisted by the existing international standards and thus imported supply from New Zealand and Canada. Warehousing in Western Australia has encouraged acceptance in project specifications. Three supply groups report investment in Australian-based assembly and manufacture.

1.3 Costs

At 35% of the weight of steel reinforcement, GFRP can be air freighted to remote locations. Bar-for-bar comparisons of products 1-3 suggest GFRP cheaper than steel N-bar at diameter 20 mm and above; and 1.7-2 X the $/m cost of steel N-bar 8-16 mm into Perth, Western Australia. As iron ore prices increase and Australian manufacture is introduced, these relativities may change. Bar-for bar comparison may not be representative of the final member cost. Environmental impact assessments indicate GFRP approximately 70% of the carbon cost of steel (29).
