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Review

Composite piles: A review

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HIGHLIGHTS

- Research findings on construction and applications of composite piles are discussed.
- SRP and hollow FRP piles have significant potential for load bearing applications.
- Composite piles materials show superior freeze-thawing properties.
- Construction issues such as core–shell debonding are discussed with solutions.
- Applicability of analytical design approaches for composite piles is discussed.

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ABSTRACT

Traditional piling in the form of steel, concrete or timber is susceptible to hazards within harsh marine environments. The deterioration of wood, corrosion of steel and degradation of reinforced/prestressed concrete piles in deep foundations has led researchers to experiment with methods to overcome these problems. Composite material piles, such as fibre-reinforced polymers (FRP) and structurally reinforced plastics (SRP), are a unique solution to the problems faced by traditional piling in marine environments. Their resistance to corrosion and long service life make them an economical and environmentally viable solution to traditional piling. Although a few manufacturers have begun to adopt some form of composite piling for fender applications, barriers remain that prevent their widespread use as load bearing piles. These barriers include the lack of specific driving and installation guidelines, limited full-scale geotechnical design data, long-term durability studies and in-depth environmental impact studies. To facilitate research in the aforementioned areas, this review paper details the historical use of composite piles, the structural and geotechnical design of several types of load bearing composite piles, the durability of piles, and, lastly, the construction and manufacturing processes involved. The findings show that there is a general consensus amongst researchers that fibre-reinforced piles (FRP) are structurally and geotechnically suitable for a range of load bearing applications, and that SRP piles, with adequate reinforcement, can potentially be used in deep foundations. More full-scale field research is still needed to develop sufficient driving guidelines, and durability tests emulating saline marine conditions should be carried out to assess the effectiveness of epoxies, and, lastly, reinforcing arrangements should be tested to prevent lateral deflection.

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Abbreviations: FRP, fibre-reinforced polymer – a composite material model with a polymer matrix reinforced do with fibres; CFRP, carbon fibre-reinforced polymer – has the highest strength to weight ratio formed by thermoset resin such as an epoxy in addition to other composites such as aramid or carbon fibre; GFRP, glass fibre-reinforced polymer – also known as fibreglass where the prime reinforcing fibre is glass; SRP, structurally reinforced plastic – recycled plastics moulded into pile shapes and reinforced with either fibreglass or steel rods.

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1. Introduction

In order to construct marine front structures, such as jetties, boardwalks or seaside buildings, deep foundations consisting of piles are needed to resist the moments and large lateral forces created by incoming waves. Modern techniques for marine pile construction date back to 1896 where over 5000 chemically treated red-gum wooden piles were driven to support the enormous San Francisco Ferry Building, and almost a century later investigators found the piles were still in perfect condition [1].

This case, however, is an exception and the majority of timber, concrete and steel piles experience shorter life spans due to corrosion, degradation and marine borer attack [2]. Early techniques for protecting piles from elemental degradation and corrosion involved methods, such as using treated timber piles or painting steel with a heavy metal coating. However, such pile protection methods are both costly and harmful to the marine environment. The increase in environmental awareness in the late 1980s was a major push for researchers to begin experimenting with composite material piles [3].

Early researchers including Lampo et al. [2], Han and Frost [4], Mirmiran et al. [5], and Fam and Rizkalla [6] who worked on tailoring the widely accepted design methods for traditional piling, e.g. Poulous and Davis [7], and Randolph and Murphy [8], in order to meet the unique nature of composite piles. A brief overview of their works is described in Section 3.

Despite the extensive research in this area, composite piles have not yet gained global acceptance as a reliable alternative to traditional piling systems in marine environments. In 2001, Iskander et al. [9] highlighted five key barriers preventing the widespread implementation of composite piles, these included:

(1) Composite pile construction and installation need to be more price competitive over a life cycle basis.
(2) Mechanical and physical properties should be defined and tested using long term performance field tests.
(3) Design methods for driveability need to be further developed.
(4) Design and testing standards should be developed.
(5) Several composite piles should be installed, load tested and monitored.

In the past 14 years, since the above barriers were highlighted, researchers, such as Pando et al. [10] and Velez [11], managed to not only test multiple types of composite pile, but also implement enhancements, which has aided in closing the gap between research and large-scale industry adoption.

2. Types of composite pile

The first type employed in marine structural applications was a steel pipe covered in recycled plastic, which was used as a fender pile in the port of Los Angeles in April 1987 [10,12]. Following the success of composite piles used for fender piles, fibre-reinforced polymer (FRP) piles were considered in the restoration