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Engineered cementitious composites for modern civil engineering structures in hot arid coastal climatic conditions

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Abstract

Engineered Cementitious Composite (ECC) is an exclusive type of cement mixture with unique composition of low volume fibers and different composites so as to impart high ductility, high tensile strength besides ability to repair. Conventional concrete and fiber reinforced concrete has brittle nature and hence crack easily under environmental and mechanical loads affecting durability of structures. Efforts to modify the brittle nature of conventional concrete resulted in development of ECCs offering durability under a broad range of environmental exposure, low embodied energy, and negative carbon footprint making it environmentally sustainable construction material with self–healing potential. ECCs demonstrate tight crack width and development of these cracks in fact increase ability of ECCs to resist effects of hot, frost and humid weather conditions besides its low permeability coefficient and higher resistance to steel corrosion compared to other common substitutes. The paper attempts to discover suitability of ECC in a typical hot arid coastal region experiencing extreme harsh climate. It bear upon an in depth review to investigate potential of ECC, influence on pertinent engineering properties and its impact on construction industry in hot arid coastal climatic conditions.

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Keywords: ECC; composites; durability; self-healing; sustainability

1. Introduction

The advances of sustainable construction and the green building movement of past decade have encouraged detailed assessment of construction practices and building materials. Globally, a number of sustainable initiatives

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emphasize on development and procurement of green materials, design of low energy demanding materials, procedures and construction practices that result in requiring lesser resources and energy and produce minimum waste. One such recent exploration in this realm has been development of Engineered Cementitious Composites (ECCs). ECCs are designed to produce a strong and ductile material that can be used in several applications where fiber reinforced concrete may not be appropriate. Generally, brittleness of concrete increases with increase in compressive strength, which is a potential restriction on the use of high strength concrete in structures. The advent of ECCs envisaged development of highly ductile cementitious materials as valuable constituent for structural and infrastructural applications having characteristics of high strength concrete besides increased tensile strain capability compared to normal or fiber reinforced concrete. Many studies focusing mechanical characteristics like residual strength, stiffness, and strain hardening of ECCs and its self–healing capabilities are carried out either in natural environmental exposures to very mild conditions where temperatures typically range from -14 to 28°C or at elevated temperatures of the order 200°C to 800°C or [1, 2, 3]. The structural characteristics of ECC in a hot arid coastal region with extreme harsh environmental conditions such as varied temperature range and humidity conditions has not been thoroughly explored. The paper presents an in depth review to investigate potential of ECCs, influence on engineering properties, and its impact to construction industry in such environmental conditions. The paper is not meant to be an exhaustive literature review of the subject matter but instead focuses on showing the diversity and breadth of this versatile and integrative material intersecting construction industries in hot humid coastal areas where temperatures remain above 45°C and humidity averaging over 90% for many days during summer, while round the year humidity averages between 50% and 60%.

Concrete is the most widely used structural construction material causing significant social, economic and environmental impacts. Globally, cement production accounts for 5% of greenhouse gases and various pollutants like significant levels of NO_x and particulates in to atmosphere [4]. It is therefore crucial that a sustainable and durable construction material like ECCs should be effectively used in any given environmental conditions so as to synergize a sustainable interaction between natural and built environment. ECCs have been identified as material greening component with overall goal of improving environmental sustainability. ECCs are high–performance fiber reinforced cementitious composites designed to resist large magnitudes of tensile and shear forces while remaining compatible with ordinary concrete in almost all other aspects such as volume usage, compressive strength and thermal properties.

2. Durability of ECC in hot and humid environments

Freeze–thaw tests are generally designed to simulate temperature changes in winter conditions. A study by Lepech and Li [5] included freeze–thaw exposure as per ASTM C666A [6] on companion series of ECC and normal concrete specimens – both without any air entrapped, as concrete durability is considered to be very sensitive to amount of air entrainment. These tests evaluated the effect of freeze–thaw conditions on strain capacity of composites. The performance resulted in a durability factor of 10 for concrete compared to 100 for ECC with both sets of specimens exhibiting a strain capacity of approximately 3%, well above the capacity needed by most structural applications.

To examine long term effects of hot and humid environments, Li et al. [7] included hot water immersion tests on the specimens. The effects were comprehensively examined on individual fibers, single fibers embedded in ECC matrix, and composite ECC specimens. These specimens were cured for 28 days at 60°C prior to hot water immersion for 26 weeks. After 26 weeks a small difference was seen in fiber properties such as strength, modulus and elongation. Interfacial properties, however, experienced significant changes, particularly between 13 and 26 weeks. During this time the chemical bonding between fiber and matrix increased, but the fiber apparent strength decreased. A drop in interfacial strain capacity from 4.5% at 13 weeks to 2.75% after 26 weeks of hot water immersion was seen. Hence, it was concluded that 2.75% of strain capacity (nearly 250 times greater than concrete) as seen after 26 weeks of accelerated conditioning, which can practically be considered equivalent to 70 years of hot and humid exposure is acceptable for almost any structural application. As a result, it should be noted that ECC exhibits exceptional behavior under freeze–thaw cycles, hot–cold temperature cycles, carbonation exposure, fatigue loading and long term mechanical performance.