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Corrosion behavior of concrete mixes with masonry chips as coarse aggregate

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HIGHLIGHTS

- Corrosion potential of embedded reinforcement in brick aggregate concrete has been evaluated.
- Brick aggregate concrete has significantly higher corrosion susceptibility as compared to stone aggregate concrete.
- Brick aggregate imparts high permeability in concrete regardless of mix proportion.
- A positive correlation exists between corrosion potential and rebar weight loss.

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ABSTRACT

This study is primarily centered towards a quantitative evaluation of the corrosion behavior of commonly used masonry chip concrete mixes as an assessor of durability performance of infrastructures. In South Asian regions like Bangladesh, the construction domain is inclined towards using masonry chips as coarse aggregate owing to its low cost and profound availability. However, reinforced concrete structures with brick aggregate impart high susceptibility towards corrosion while putting long-term sustainability at stake. This phenomenon is further prominent in the coastal areas where high saline conditions are prevalent. Meanwhile, there is no significant study available to assess the corrosion behavior of commonly used masonry chips which is relatable to the degree of durability degradation. Hence, a comprehensive study has been designed to infer the corrosion characteristics of concrete mixes made with brick aggregate in saline environment by using an accelerated corrosion technique. Corrosion proneness of different concrete mixes with a variation in water-cement ratio and mix proportion was analyzed within the scope of this study. An overall comparison of the corrosion performance of brick aggregate was also made to the similar behavior of stone aggregate to have a comparative overview of the durability performance of the commonly used aggregates in concrete mixes. Furthermore, an insightful correlation has been obtained between the corrosion potential readings and weight loss of the embedded rebar which can be used as a quantitative basis to deduce the durability of a structure. Thereby, this project suffice as an initial study to provide a clear understanding on the corrosion performance of commonly used concrete mixes and as an aid for an early in-situ evaluation of the health of infrastructures.

1. Introduction

With the advent of time in this modern era of Civil Engineering, infrastructural sustainability is gaining its significance as the core of global concern [1]. The distress of this comprehensive issue is further aggravated by a global climate change, whose alarming rate is obliging it to the brisk of constructional apprehension nowadays [2]. As a remedy to this emerging problem, assurance of long term durability of Reinforced Concrete infrastructures is the key and prime focus of a sustainable constructional practice [3]. However, in South Asian regions like Bangladesh, the constructional domain is not often centered towards this substantial issue where the dispute between a proper mix design and a sustainable infrastructure

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remains unresolved. This scenario is profoundly significant in the remote or coastal areas where the prevalent constructional practice is focused on the use of locally available masonry chips [4,5]. The use of such materials can be attributed to the ease of availability with underlying advantage of low transportation cost and an economic constraint towards the use of superior materials, [6,7]. In a brick industry, it is a common practice to discard those samples marked with a certain level of nonconformity resulting from irregular temperature control and over burning. The use of such bricks as coarse aggregate serves as efficient means of waste disposal and a low-cost source of aggregate [6,8]. In the present construction norm where strength is deemed as the key priority, a mix of cement and water with masonry chips and local sand is used following some predetermined volume fraction without any strict adherence to the standard codes of practice [4,5]. The use of highly permeable masonry chips in concrete structures imparts a relatively lower compressive strength and durability to the concrete structures while exposing them to vulnerable degradation in presence of aggressive deteriorating environment. This scenario is more apparent in the coastal areas where the concrete structures with brick aggregate are highly susceptible to corrosion attack of embedded reinforcements [9–13]. Such phenomenon is common to reinforced concrete bridges in saline areas which exhibits a lifetime expectancy much less than normal, resulting in poor serviceability and greater indirect cost [14,15]. Brick aggregates possess high permeability which usually results in a significant amount of chloride ion ingress into concrete structures making them more corrosion prone. The resulting higher concentration of chloride ions reduces pH of the surrounding concrete and destroys the passive oxide film around rebars which is inherent to a well cured alkaline concrete [16,17]. The resulting products of corrosion lead to cracking and spalling of the surrounding concrete due to the expansive forces exerted by an increase in volume [14,18]. Although there have been a considerable number of studies regarding the permeability of brick aggregates, the depth of knowledge of the corrosion behavior of brick aggregate concrete and its correlation to other properties is significantly limited. In this regard, a comprehensive analysis is optimal for commonly used concrete mixes on the basis of all criteria and with sufficient quantitative justification to validate the findings on corrosion behavior of masonry chips. The outcome can act as an aid during construction of an infrastructure where a holistic durability behavior of the construction ingredients is a prerequisite. Hence, this project has been undertaken as an initial study in this domain which will unveil the corrosion characteristics of brick aggregate concrete quantitatively and extent of its suitability in construction.

Based on the research targets of providing a vivid picture of the suitability of commonly used concrete mixes in the country and to infer a quantitative reasoning, several preliminary researches had been conducted by the authors with concrete mixes incorporating the commonly used aggregates (bricks and stones), mix ratios and construction standards [5,8,19]. A more comprehensive approach has been taken in this article including major aspects of the concrete mixes like corrosion susceptibility, compressive strength, sorptivity and permeability to have a holistic review of the performance of these mixes. Since the ingress of chloride ions and subsequent depassivation is a long term process, the corrosion phenomenon was analyzed by using an accelerated corrosion technique. The underlying mechanism of the technique, the experimental setup used and corrosion potential of some of the common concrete mixes had been overviewed to some extent in previous studies by the authors [5,8,20]. This article explains and summarizes the corrosion behavior of typical mixes based on findings of the previous studies [8,19] as well as results obtained from new mixes. Moreover, in this study, the corrosion behavior of the concrete mixes was quantified with respect to other properties of the mixes to provide a general numerical comparison basis between brick and stone aggregate. Considering outcomes from previous studies and the extended findings in this research, the use of brick aggregate conformed to a wide range of difficulties, where corrosion problems of reinforced concrete structures seemed significant. The quantitative assessments of the performance of the concrete mixes yield a comprehensive understanding of the common problems associated with the use of locally available materials (masonry chips) as compared to stone aggregate. Hence, this research work was implied in decoding the situations where the locally available aggregates can be used and the extent to which they can be used to ensure optimum sustainability.

2. Test program

The whole experimental program consisted of four different stages:

(a) Accelerated Corrosion Testing: Accelerated Corrosion is practiced often as a means of inducing corrosion in concrete specimens within a short range of time. The concrete samples were immersed in a 5% NaCl [21,22] solution and were subjected to a constant voltage of 12 V [21], with the purpose of simulating the saline environment effect.
(b) Measurement of Half-Cell Potential Reading: Half-Cell potential readings were taken using a Half-Cell potentiometer (HCP) at different points on the concrete prisms to quantify the high impedance potentials in concrete [23], which point to probability of corrosion [24].
(c) Test on Concrete Cylinders: Three different tests were performed to measure strength and permeability:
    (i) Rapid Chloride Permeability Test (RCPT): Concrete cylinders were subjected to a RCPT test, after 90 days of casting, inferring about their permeability as per ASTM C1202 [25].
    (ii) Compressive Strength Test: Cylinders were tested in Universal Testing Machine as per ASTM C39 – 14a [26], after 7 and 28 days of casting, to observe their relative strength.
    (iii) Sorptivity Test: Concrete cylinders were subjected to Sorptivity Test, after 28 days of casting as per the specifications of ASTM C1585 [27]. This test measures concrete property which represents its tendency to absorb and transmit water [28].
(d) Weight Loss Measurement: Weight loss of embedded rebar due to corrosion effect was measured to establish a correlation.

3. Materials and concrete mix design data

In this study, the concrete specimens were prepared using Ordinary Portland Cement (OPC), similar to type I, as the binding agent with corresponding values of 3.15 and 1440 kg/m^3 for specific gravity and unit weight, respectively. The fineness value of the cement used, obtained by Blaine test as per ASTM C204 [29], was 287.7 m^2/kg while the 7th and 28th day strength, obtained as per ASTM C109 [30], was 4833 psi and 6190 psi, respectively. The concrete specimens were prepared with both stone and brick aggregates having a maximum particle size of 19 mm. Some basic properties of aggregates (brick and stone) such as crushing strength, impact values, flakiness index, percent abrasion values, absorption, specific gravity and unit weight (shown in Table 1) were assessed as per the specifications of BS 812 (part 3), BS 812 (part 1), ASTM C131, ASTM C127 and ASTM C29, respectively [31–35]. Sylhet Sand was being used as the fine aggregate in the