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Evaluation of sustainable concrete produced with desalinated reject brine

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Abstract

The worldwide demand for new concrete buildings is increasing at a rapid pace to keep up with urban development. Despite the need, concrete production and its use have a number of environmental consequences. The production of concrete creates a substantial need for water that directly causes a burden on the already scare natural resource. In United Arab Emirates the majority of the water used for concrete production is obtained through desalination of the seawater. Desalination of seawater produces highly saline wastewater commonly known as reject brine or concentrated brine that has numerous negative environmental effects. The production of cement, the primary ingredient in the production of concrete is responsible for the generation of nearly 5% of the global carbon dioxide that is a potent greenhouse gas.

With the intent of reducing the carbon footprint of concrete production, a study was carried out to determine the effect of using reject brine as the source of water and the use of ground granulated blast furnace slag (GGBS) as a replacement for cement. Concrete samples having three different cement contents were prepared with normal tap water and reject brine. Results showed that the use of GGBS and reject brine improved the strength of concrete produced by 16.5%. Replacing 50% of the cement with GGBS and using reject brine as the source of water has a potential for reducing 176 kg CO_2 and 1.7–3.4 kg of CO_2 equivalents per one cubic meter of concrete, respectively. The use of the waste reject brine can potentially save USD 170–340 per cubic meter of concrete produced.

Keywords: Concrete; GGBS; Brine; Reject water; Sustainability

1. Introduction

Although essential to sustain life on earth, fresh water is increasingly depleted with time. The demand for fresh water has been on a continuous rise as a result of increased population, industrialization, motorization, and increased standards of living. According to statistical estimations of the United Nations Organization (UNO), approximately 1800 million people around the world will be subjected to severe water scarcity by the end of the year 2025 (Sharon and Reddy, 2015). Therefore, the society and the scientific community have become aware, more than ever, of the societal and the industrial importance of fresh water. The concrete industry uses large amounts of fresh water for mixing, curing, and cleaning purposes. Being the primary building material in construction, concrete production con-

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sumes several billion tons of fresh water every year which has caused ever-increasing pressure upon fresh water resources (Nishida et al., 2015). In order to conserve fresh water, researchers are continuously investigating alternatives to fresh water for use in concrete.

Countries close to the ocean and lacking sweet water often resort to seawater desalination for producing potable water for human consumption. This high quality produced water is usually used for concrete preparation. Conventional seawater desalination methods include multistage flash distillation (MSF), reverse osmosis (RO), multi-effect distillation (MED), and electro-dialysis (ED) Ali et al. (2011). These desalination techniques produce fresh or pure water from seawater, but at the same time the processes result in the production of a hypersaline by-product waste known as reject brine. After extraction of pure water, the reject brine (also known as reject water, concentrate, or brine) has a higher salt concentration compared to the feed seawater. Depending on the type of desalination process utilized, only 35-45% of pure water can be recovered from seawater while the remaining 55–65% of the feed exits the desalination plant as reject brine (Shammas et al., 2011). The reject brine is usually discharged back into the marine environments resulting in detrimental physiochemical and ecological impacts (Roberts et al., 2010). Similar to the problem of water scarcity, the detrimental effects of the reject brine on the aquatic environments represent a serious environmental problem, and the researchers are continuously exploring new and sustainable method for the management, disposal, and handling of the reject brine.

With rapid industrialization and urban development, the need for concrete has never been greater, with more than a ton of the concrete being used per capita globally (Radonjanin et al., 2013). Concrete is usually produced using Portland Cement (PC). However, the use of this cement is not very environmental friendly. The production of Portland Cement is a highly energy-intensive process and consumes approximately 4–7 MJ of fossil fuel energy per kilogram of Portland Cement produced (Maier and Durham, 2012; Swamy, 1988). The Portland Cement is also a significant contributor to the release of the greenhouse gases (Collins and Sanjayan, 2002). It has been suggested that the production of cement alone is responsible for 5% of the greenhouse gas production on a global scale (Collins and Sajayan, 2002; Worrel et al., 2001). Due to the negative impacts on nature, there is a gradual shift from the traditional concrete preparation of using cement to the use of other materials. Sustainable production of concrete is itself a challenge for the researchers.

Ground granulated blast furnace slag (GGBS) is a waste produced in the manufacture of iron. GGBS is primarily a mixture of lime, silica and alumina that is also found in Portland Cement. However, the percentages of the materials in GGBS are not in the same proportions that exist in Portland Cement. The typical particle sizes of the slag are in the range of 10–45 microns. Replacing some amount of PC by GGBS in concrete adds favorable advantages, such as improving workability and durability of the resulted concrete. In addition to improving the physical properties of concrete, GGBS has a lower carbon footprint compared to PC. The carbon footprint of producing one ton of GGBS is 0.07 ton of CO_2 equivalent compared to 0.95 ton for one ton of PC. Therefore, replacing PC with GGBS will result in lower carbon emission (Higgins, 2006). Research has shown that slag concrete mixes significantly reduce the carbon footprint. For example, Elchalakani et al. (2014) studied 14 types of concrete mixes made with high volume of GGBS in order to reduce the emission of carbon and greenhouse gases. These concrete mixes were divided into medium, high, and low volume cement content of 360, 400–440, and 300–340 kg/m^3, respectively. The results indicated that the concrete mix with 100% Ordinary Portland Cement (OPC) resulted in the highest CO_2 emission of 386 kg/m^3. The most economical mix was found to be 80% GGBS and 20% OPC that resulted in CO_2 emission of only 154 kg/m^3. Nevertheless, the paper highlighted the fact that CO_2 emission and the CO_2 intensity indicator values are lower when GGBS is used compared to 100% OPC.

With a combined thought on the two aforementioned research concerns and problems, an investigation into the possibility of using desalination reject brine as mixing water in concrete has become of increasing interest to the authors of this paper. The use of reject brine in mixing concrete will serve two main purposes. First, the consumption of fresh water in concrete industry will be decreased which will release some pressure on the limited potable water resources. Second, the detrimental physiochemical and ecological impacts of the reject brine on the receiving water bodies will be reduced. The use of saline water for preparing concrete is not new. Kaushik and Islam (1995)) highlighted the effect of using saline water on the setting time of concrete. In their study Mori (1981) found relatively small difference between in the strength of concrete prepared with saline water and concrete prepared with fresh water. However, Yamamoto (1980) observed that the concrete mixed with saline or salty water shows higher strength relative to concrete mixed with fresh water under experimental temperatures of less than 15 °C. Neville (2001), for example, recommended avoiding the mixing of saline water with concrete reinforced with steel bars in order to prevent consequences of metal corrosion. However, long-term exposure research by Otsuki et al. (2011) and Nishida et al. (2015) showed that the perceived negative influence of chloride ions from seawater used for concrete preparation is relatively small or negligible. In another study, the authors concluded that steel corrosion in reinforced concrete structures might not be due to the presence of chloride ions in the water but due to suphate attack as a result of exposure to the harsh marine environment where the structure was located. The research by Nishida et al. (2015) carried out both literature-based study and experiments on the use of