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Review

Use of sea-sand and seawater in concrete construction: Current status and future opportunities

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HIGHLIGHTS

- Effects of sea-sand and/or seawater on the properties of concrete are summarised.
- Admixtures can enhance the performance of concrete with sea-sand and/or seawater.
- Combination of sea-sand seawater concrete with FRP leads to sustainable structures.
- Sea-sand seawater concrete incorporating recycled coarse aggregate is attractive.
- Research needs and application opportunities are discussed and recommended.

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ABSTRACT

This paper presents a critical review of existing studies on the effects of using sea-sand and/or seawater as raw materials of concrete on the properties of the resulting concrete, including its workability, short- and long-term strength as well as durability. It has been shown by existing research that concrete made with sea-sand and seawater develops its early strength faster than that of ordinary concrete, but the former achieves a similar long-term strength to the latter. Existing studies have also shown that the use of sea-sand and seawater may have a significant effect on chloride-induced steel corrosion but has only a negligible effect on the carbonation process of concrete. Strong evidence exists that a combination of mineral admixtures for the concrete and reinforcement with fiber reinforced polymer (FRP) can effectively solve the durability problem associated with the abundance of chloride ions in sea-sand seawater concrete (SSC). Such use of SSC also offers a good opportunity for the incorporation of recycled coarse aggregate (RCA) in concrete, particularly those that have been chloride-contaminated, as has been demonstrated by some preliminary research. The current understanding of the behavior of SSC, as summarized in the present paper, provides a solid basis for further research in the area to enable the wide use of SSC in concrete construction worldwide, particularly when combined with FRP as the reinforcing material.

Contents

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1. Introduction

In the year of 2016, the amount of cement produced in the world reached 4.20 billion tonnes [1], and the estimated concrete production was around 25 billion tonnes. The production of aggregates (including both coarse and fine aggregates) reached about 40 billion tonnes in the year of 2014 [2]. In particular, the consumption of concrete by mainland China and other developing countries has increased rapidly over the past few decades. Fig. 1 presents the per capita amounts of ready-mixed concrete produced and its constituents (including river sand and freshwater) consumed in mainland China over the past five years [3]. The consumption of tremendous amounts of raw materials, particularly river sand and freshwater, in concrete production has raised serious environmental concerns. Extraction of river sand as fine aggregate impacts negatively on river ecosystems, navigation and flood control. As a result, China has issued some regulations on sand-mining banning from the Yangzi River due to environmental considerations, such as No. 320 Decree by the State Council of the People's Republic of China in year 2001. Similarly, the consumption of a great amount of freshwater poses a great challenge due to water shortage in many parts of the world. Besides sand and water, consumption of the other main constituents of concrete (i.e., coarse aggregate and cement), has also caused major environmental concerns, but the present paper is mainly concerned with alternative solutions for sand and water.

The lack of river sand has led to the use of sea-sand and crushed stone fines in many countries, with the use of sea-sand in the UK being an example [4]. More than 90% of the world's dredged sea-sand has been used as a raw material in the construction industry, with over 45% of the dredged sea-sand being used as fine aggregate for concrete [5]. Fig. 2 illustrates the situations of sea-sand exploitation in different countries and regions, where the dredged sea-sand is mainly used as a raw material in construction [6]. Infrastructure development in the UK, the airport in Hong Kong, the city expansion in Singapore and the vast reclamation projects in the Middle East are only some of the typical examples of successful use of sea-sand as a raw material in civil engineering [7–9].

The UK was the pioneer country to use desalted sea-sand as fine aggregate in concrete [10]. In the 1960s, British experts conducted a series of studies on the use of sea-sand as a raw construction material [10–13]. Over 21 million tonnes of sea-sand and gravel was extracted annually around the coast of England and Wales from 2000 to 2004. On average, desalted marine aggregates accounted for approximately 17% of the total amount of fine aggregate and gravel used in concrete production in England and Wales [14].

As early as 1973, desalted sea-sand also became one of the main sources of fine aggregate in concrete production in Japan [15]. In 2011, approximately 70 million tonnes of fine aggregate was used in producing ready-mixed concrete in Japan, with desalted sea-sand accounting for 12.2% (8.54 million tonnes), river sand 13.9%, mountain sand 40.2% and manufactured sand 33.6% [16].

Since the 1990s, due to the scarcity and rising price of river sand in mainland China, many coastal areas began to use desalted sea-sand as fine aggregate in concrete for buildings and civil infrastructure projects, such as Majishan Port of Shanghai Bao Steel Group [17]. It has been reported that within a distance of 5 m–50 m of

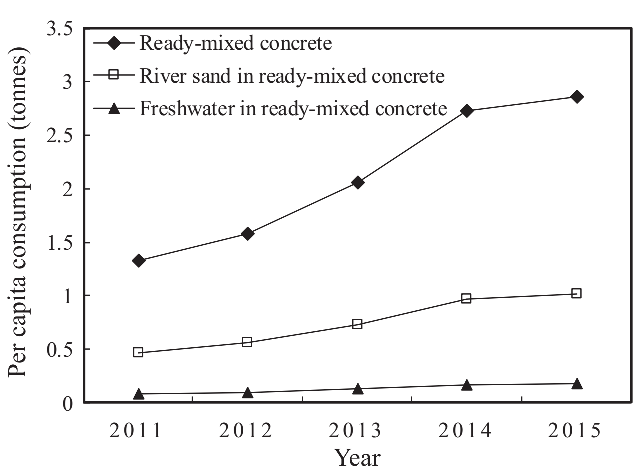

Fig. 1. Per capita amounts of ready-mixed concrete produced and constituent materials consumed in mainland China*. *The population from 2011–2015 was from the National Bureau of Statistics of China. The per capita amounts consumed of sand (fine aggregate) and water for ready-mixed concrete production were calculated by assuming that the density of ready-mixed concrete is 2400 kg/m^3 and that 150 kg of water and 850 kg of sand are needed for producing 1 m^3 of ready-mixed concrete.

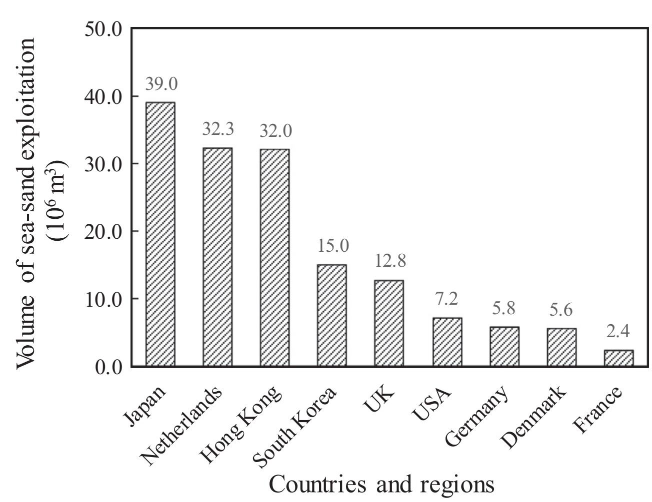

Fig. 2. Sea-sand utilization in different countries and regions (adopted from Ref. [6])*. *Data sources: Japan, from 1998; Hong Kong, averaged over 1990–98; South Korea, averaged over 1993–95; Germany, from 2000; and other counties, from 2002.