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Discussion and experiments on the limits of chloride, sulphate and shell content in marine fine aggregates for concrete

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HIGHLIGHTS

- Limit values of chloride, sulphate and shell contents in the marine aggregates in different countries were discussed.
- A better understanding on the rationale behind the limit values was provided.
- An experimental study was carried out to evaluate the rebar corrosion in concrete mixed with DMS.
- This study can contribute to fill the knowledge gap on DMS application and relative research.

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ABSTRACT

Concrete is the most consumable building material in the world. Marine aggregates are the natural sand and gravels available in the sea or dredged from seabed. Contents of chloride, sulphate and shell in the marine aggregates can influence the properties of concrete and corresponding performance of the concrete structures. However, the limitations of chloride, sulphate and shell contents are set as different threshold values in different countries and/or regions. Some of them are inconsistent or puzzling for user. This paper presents a comprehensive review on the limit values of these contents used in different countries and provides a better understanding on the rationale behind these limit values thorough analysis on the limits of chloride, sulphate and shell content in marine fine aggregates for concrete. Except discussion, in this paper, an experimental study was carried out to evaluate the corrosion of reinforcing steel in concrete mixed with DMS as well. The experimental results of corrosion potential and corrosion current density showed that the rebar in DMS concrete should be safe from corrosion when the chloride content in DMS is less than 0.18% or the total chloride content in concrete is less than 0.34%. This study can contribute to fill the knowledge gap on concrete applications on dredged marine sand (DMS) and relative research.

1. Introduction

Marine aggregates are the sand and gravels naturally found in the sea or dredged from seabed. They can be used as aggregate in concrete after appropriate desalting treatments. Marine aggregates hold a large proportion of construction sand and gravels in the world due to the shortage of inland aggregates. For example, based on the data published in BMAPA UK, in England and Welsh, marine aggregates occupy approximately 20% of the total consumption of sand and gravels used in concrete. Especially in London, marine aggregates occupy about 50% [1]. In Japan, marine aggregates were used as fine aggregates in concrete with a proportion of 25–40% in the 1970s and 1980s [2]. Many countries have reported their use of dredged marine sand (DMS) in construction; examples include European countries such as Netherlands, Denmark, Belgium, and Spain [3–6], and Asian countries such as Sri Lanka [7] and Turkey [8]. In China, most of DMS is used as fine aggregate in concrete, while a small part of it is used for sea reclamation. According to the report of Chinese Marine Economic Statistics Bulletin in 2015, the annual value of marine mining production based on DMS was about 67 billion Chinese Yuan (about 10 billion US dollar) with an annual growth rate of 15.6% [9].

Unlike river sand, DMS contains soluble salts and shell which restrict its direct use in concrete. For example, sulphate ions can react with calcium hydroxide to form calcium sulphate (gypsum),

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which subsequently reacts with tricalcium aluminate (C_3A) to form ettringite thus damage concrete [10]. Shell may affect the properties of concrete including workability, strength, durability etc. due to its slice and hollow shape [11,12]. Additionally, chloride salt content in DMS makes a larger effect on the properties of concrete, including the hydration of Portland cement [13] and the corrosion of reinforcing steel embedded in concrete [7,14,15]. In order to guarantee the quality of concrete used in a construction project, the national standards in many countries have limited the contents of chloride salt, sulphate salt and shell in DMS used for concrete. However, the limit values and the criteria defining the limit values are significantly different in different standards. If the limit values are not properly established or not adequately implemented, it may affect the quality of produced concrete and cause potential hazards to the durability and safety of concrete structures. Typical examples are the "Marine Sand House" in Taiwan and the buildings damaged in 1998 Adana-Ceyhan and 1999 Izmit earthquakes in Turkey [16]; both of which used the concrete with DMS.

In order that the DMS can be used safely in concrete structures, this paper reviews the current state of using DMS in different countries and compares the limit values set in the national standards for various harmful substances such as chloride content, shell, sulphate salt etc. in marine sand. Analysis is performed on the criteria defining these limit values and the rationality behind the criteria is also evaluated. In addition, an experimental study was carried out to evaluate the corrosion of reinforcing steel in concrete with DMS.

2. Limits on chloride content

UK, Japan and China are the main countries that allow for the use of DMS in concrete. The national standards in these countries provide the limit values of chloride content in aggregates used for concrete. However, the national standards in some other countries including USA, Germany and France (before the European standard was implemented) do not provide the limit values of chloride content in aggregates used for concrete. Table 1 provides a comprehensive comparison of the limit values of chloride content in aggregates used for concrete recommended by different national and/or different regional standards.

2.1. British and European Union standards

The UK is the early country in Europe who uses marine aggregates and also is one of the most successful countries which use marine aggregates for concrete. Since 1970s, marine aggregates have gradually become the significant resources of construction aggregates in the UK [31]. In order to control the corrosion of reinforcing steel caused by the use of marine aggregates, the limit values of chloride content in marine aggregates including the compound DMS and gravels were incorporated into the amended British Standard BS 882: Specification for aggregates from natural sources for concrete in 1983 [17]. According to the type and/or the use of concrete, limits of chloride content were given for four categories of concrete: 0.02% for pre-stressed concrete and steam-cured structural concrete, 0.04% for structural concrete made with SRPC, 0.06% for structural concrete with Portland cement, and no limit for other concrete containing no embedded metal. The notes of BS 822 show that the limits in specification are derived from those in CP 110: Part 1 [32] for the total chloride content of concrete. In the 1992 amendment edition of BS 882 [18], the limit values of chloride content in marine aggregates were decreased by 0.01%. However, it is interesting that the limits

Table 1
Limits on chloride content in nature aggregates.

Nation or region	Code		Application or Category[a]	Limits/%	Comment [b]
British	BS 882-1983 [17]		PC & heat-cured RC	0.02	Cl^-,
			Concrete with SRPC	0.04	combined aggregate
			RC with Portland cement	0.06[c]	
			Other concrete	No limit	
	BS 882-1992 [18]		PC & heat-cured RC	0.01	
	(Replaced by EN 12620-2002) [19]		RC with SRPC	0.03	
			RC with other cement	0.05	
			Other concrete	No limit	
British & European Union	BS EN 12620-2002/2013 [19]		If $Cl^- \le 0.01\%$, this value can be used to calculate the chloride content in concrete	No limit	Limits in the concrete
Japan	JASS 5	1957 [20]	Concrete	0.01	NaCl,
		1975 [21]	General conditions	0.02	dry sand
			With auxiliary condition	0.1	
		1979/2009 [22]	General conditions	0.04	
			With auxiliary condition	0.1	
	JIS A 5308-1978 [23]		PC	0.02	
	JIS A 5308-2009 [24]		PC + Customer's approval	0.03	
			RC	0.04	
			RC + Customer's approval	0.1	
Taiwan	CNS 1240 A2029	1983 [25]	PC	0.012	Cl^-
			Other concrete	0.024	dry sand
		2014 [26]	Concrete	0.012	
Hong Kong	CS3-2013 [27]		PC & heat-cured RC	0.01	Cl^-,
			RC with SRPC	0.03	combined aggregate
			RC with other cement	0.05	
			Other concrete	No limit	
China	GB/T 14684-2011 [28]		Grade I	0.01	Cl^-
			Grade II	0.02	dry sand
			Grade III	0.06	
	JGJ 52-2006 [29]		PC	0.02	
			RC	0.06	
	JGJ 206-2010 [30]		PC with DMS	forbidden	
			RC with DMS	0.03	

[a] PC: Prestressed Concrete; RC: Reinforced Concrete; SRPC: Sulfate-resisting Portland Cement.
[b] Mass concentration ratio: NaCl: Cl^- = 1:0.606 or 1.649:1.
[c] 0.06 for 95% of test results, with no result greater than 0.08.

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