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Effect of salty freeze-thaw cycles on durability of thermal insulation concrete with recycled aggregates

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HIGHLIGHTS

- Effect of salty freeze-thaw cycles on RATIC and the mechanism was tested.
- Recycled aggregates have huge effect on RATIC after salty freeze-thaw cycle.
- Failure form of recycled aggregate concrete differs from normal concrete.
- The old ITZs aggravate the damage of RATIC in harsh environment.

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ABSTRACT

An experimental study on the durability of thermal insulation concrete with recycled aggregates (RATIC) subjected to the combined action of chloride salt erosion with 3.5% NaCl solution and freeze-thaw cycles (referred to as salty F-T cycles) has been carried out. In this study, the volume of the natural coarse aggregates has been replaced by recycled coarse aggregates (RCA) at replacement rates of 0%, 30%, 50%, 70%, and 100%. The results show that thermal insulation aggregate glazed hollow beads (GHBs) had a positive effect on the durability of concrete and RCA had an enormous negative influence on the durability of RATIC exposed to the salty F-T cycles. After 100 salty F-T cycles, the relative dynamic modulus of the elasticity of samples with RCA was below 60% compared to at the start of the F-T cycles. RCA has a significant effect on the chloride permeability of RATIC compared to natural aggregates. This phenomenon was caused by the special multi-interfaces structure of RATIC that are the result of the old interfacial translation zones (ITZs). These aggravate frost damage and negatively affect the durability of concrete in the salty F-T cycles environment.

1. Introduction

Concrete is a type of composite material in which cement, aggregate, and water are mixed together. The aggregate in concrete plays a key role and occupies the largest volume [1]. In the entire world, especially in developing countries such as China, the rapid development of the construction industry has consumed excessive natural resources, resulting in the deterioration of the environment. This is in contrast to the notion of sustainable development. Also, due to the construction and demolition of structures, a large volume of concrete waste is produced. This concrete waste has placed a great burden on the infrastructure of waste management as the available landfill space is limited. According to the statistics, approximately 1.55 billion tons of construction and demolition waste is produced annually in China [2]. The reuse of waste concrete material such as aggregates has attracted increasing attention due to its environmentally friendly characteristics. Over the past two decades, the effect of recycled coarse aggregates (RCA) on mechanical properties and durability has been extensively investigated and the efficiency of its use in buildings has been demonstrated [3–6].

Thermal insulation concrete with recycled aggregates (RATIC) is an innovative material in which both RCA and insulation aggregates are used to alleviate the environmental impact and improve the energy efficiency inside buildings [7]. Earlier studies showed that the mechanical properties and seismic performance of the RATIC with an optimal mix proportion design are comparable those of the normal concrete (NC) [8,9]. Therefore, RATIC may be deemed as a functional recycled aggregate concrete (RAC) or a structural concrete, which satisfies the loadbearing requirements.

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Table 1
Properties and constituents of cementitious materials.

Materials	Ignition loss	Specific surface area (m^2/kg)	Constituents (%)				
			SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
Cement	2.86	345	22.53	4.42	2.06	61.71	4.55
Silica fume	1.95	16,500	87.68	0.93	1.23	0.86	0.33

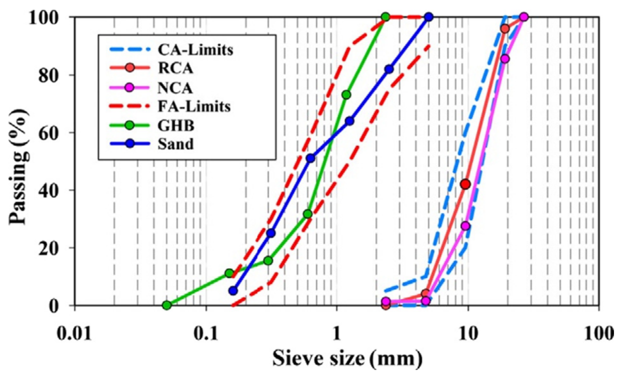

Fig. 1. Sieve analysis curves for the various aggregates.

Table 2
Physical properties of aggregates.

Type	NCA	RCA	FA
Particle dry density (g cm^{-3})	2.60	2.45	2.65
Loose bulk density (g cm^{-3})	1.43	1.17	1.45
Water content (%)	1.1	1.6	0.8
Water absorption (1 h, %)	2.5	4.8	3.5
Water absorption (24 h, %)	2.5	5.2	3.6
Fine powder percentage (%)	0.9	2.8	–
Sediment percentage (%)	0.67	0.54	2.7
Crushing index (%)	9.4	13.8	–
Shape index (%)	13.6	16.8	–
Loss of mass (%)	5.7	9.2	6.1

Fig. 2. Glazed hollow beads.

In comparison with natural aggregates, RCA are more porous and their surfaces are covered with old cement paste. This is because the microstructure of interfacial translation zone (ITZ) of RAC differs from that of NC [10]. Furthermore, the physical properties of RCA are different from that of normal aggregates. Therefore, the effect of RCA on the durability of concrete is an important issue. With internal honeycomb pores and vitrified closed surfaces, insulation aggregate glazed hollow beads (GHBs) have good water-keeping ability and stable structure. An earlier study showed that the GHB in concrete can reduce frost damage and improve frost-proof durability [11]. Therefore, with multiple interface and special inner pore structure, the durability of RATIC has important theoretical value.

Many factors affect the durability of concrete, such as chloride ion corrosion, freezing and thawing, abrasion, carbonation, absorption, and drying shrinkage. Of all these factors, chloride ion corrosion and freeze-thaw cycles have the most damaging effects on concrete. There are a number of studies on these two factors on the durability of RAC in China and other countries [12–18]. A number of experiments have been conducted to investigate the chloride permeability and freezing and thawing resistance. The results showed that reducing the W/C ratio could improve the durability of RAC and the RCA replacement percentage has a remarkable effect on durability [18,19]. This may be due to the multiple interface structure of recycled aggregates in RAC. However, in practice, concrete structures are often damaged by several factors operating simultaneously, such as the combined action of chloride-ion erosion and freeze-thaw cycles (hereafter referred to as salty F-T cycles). Therefore, it is important to investigate the durability of concrete that consists of RCA and is simultaneously damaged by several factors.

In cold areas, especially in coastal regions, the damage is usually synergistic by the salty F-T cycles. Many studies have reported the durability of NC under the salty F-T cycles [20–23]. Wei et al. [24] studied both normal concrete and high strength concrete under salty F-T cycles found mortar scaling to be the main damage form. However, there are few studies on the durability of RAC exposed to multiple environments. It is generally believed that similar to NC, the mechanical property of RCA deteriorates in a harsh environment. However, due to the multiple interface structure of recycled aggregates in RAC, it is difficult to compare the failure mechanism and quantify the performance of RAC to those of NC. As already known, two types of interfaces exist in RAC: (1) the old interfacial transition zones (ITZs) between the old cement mortar and the natural aggregate, and (2) the new ITZs between the new cement mortar and the old cement. In RAC, the porosity in the ITZs is much higher than that in the other zones. Hence, the strength of the ITZs is lower than that of the other zones [25]. Earlier studies showed that the failure behaviors of the RAC depended on the relative quality of the old ITZs and the new ITZs [26]. However, only few studies reported the effect of the ITZs on the durability of RAC subjected to the combined action of chloride salt erosion and freeze-thaw cycles.

The purpose of this study is to establish a database of durability of the relatively new RAC after been exposed to the salty F-T cycles. The mass loss rate (MLR) and the relative dynamic modulus of elasticity (RDME) have been used to evaluate the durability of RATIC.