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Enhancement of shrinkage behavior of lightweight aggregate concretes by shrinkage reducing admixture and fiber reinforcement

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HIGHLIGHTS

- We studied lightweight aggregate concretes (LWACs).
- Shrinkage reducing admixture (SRA) and steel fiber (SF) were used in LWACs.
- Effect of SRA and SF was examined on the shrinkage behavior of LWACs.
- Restrained and free shrinkage behavior of LWACs were evaluated.
- SRA modified LWACs revealed comparable shrinkage performance to those with SF.

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ABSTRACT

This paper presents the results obtained from an experimental study conducted to investigate the effect of shrinkage reducing admixture (SRA) and steel fiber addition on the performance properties of lightweight aggregate concrete (LWAC). Total of seven LWAC mixes with SRA or steel fibers were produced at the same water-cement ratio using cold-bonded fly ash coarse aggregates. The percentage of steel fiber volume fractions used in the mixes was 0.25, 0.75 and 1.25. The amount of SRA used in the mixes was 0.75%, 1.5% and 3 % by weight of cement. Ring type specimens were used for the restrained shrinkage cracking test. At the same time, free shrinkage and weight loss of LWACs were measured. Moreover, the compressive and split tensile strength tests were undertaken. The results indicated that the use of steel fibers has little effect on compressive strength but it improves the split tensile strength. The addition of SRA decreases compressive strength without affecting tensile strength. Moreover, the utilization of steel fiber or SRA extends the cracking time and reduces the crack width of LWAC resulting in finer cracks associated with lower free shrinkage.

1. Introduction

The utilization of lightweight aggregate concrete (LWAC) for structural purposes especially takes place in some of the constructions where the dead weight of concretes is the major part of the total load. LWAC which can easily be produced in the strength range of 30–80 MPa has some certain characteristics unlike the normal weight concrete (NWC), namely, low unit mass, well reinforcing steel–concrete connection, durability performance, tensile strain capacity, and fatigue resistance [1–5]. Since the wide variety of the lightweight aggregate produces some distinctive individual behavior among LWACs, the characteristics of LWAC should be studied independently for every kind of lightweight aggregates [6].

Shrinkage cracking in concrete structures may cause to accelerate other forms of damage in concrete (e.g., corrosion, freezing and thawing) and subsequently shorten the service life of structures [7–9]. Shrinkage cracking can potentially be reduced by introducing a shrinkage reducing admixture (SRA) in concrete mixtures. When concrete is losing moisture (i.e., through drying or self-desiccation), SRA significantly reduces the magnitude of capillary stresses and shrinkage strains by lowering the surface tension of concrete's pore fluid [10–13]. The other way of reducing the shrinkage cracking may be adding steel fiber in concrete mixtures. Additions of steel fiber to concrete can be an effective way to enhance the concrete's tensile stress, fracture toughness, impact strength and durability [14–16]. The properties and performance of fiber reinforced concrete vary in terms of the variations in the

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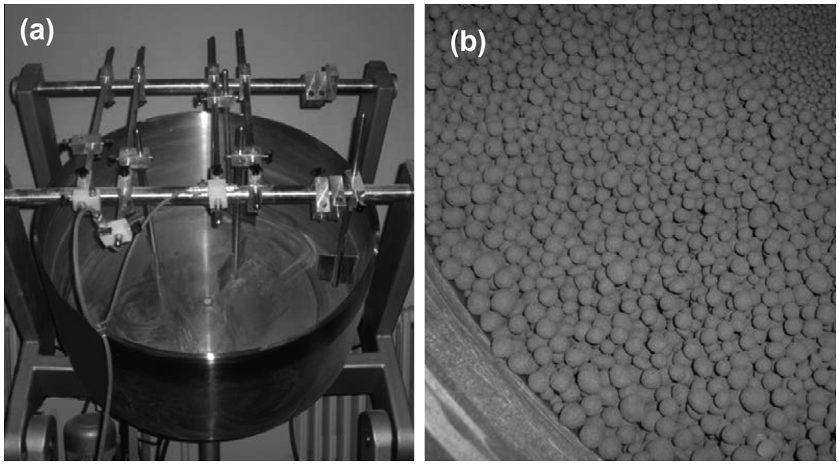

Fig. 1. (a) The general view of the pelletization disc and (b) the cold-bonded lightweight aggregate produced.

Table 1
Chemical compositions and physical properties of Portland cement and fly ash.

	Portland cement	Fly ash
Chemical compositions (%)		
CaO	62.58	4.24
SiO_2	20.25	56.2
Al_2O_3	5.31	20.17
Fe_2O_3	4.04	6.69
MgO	2.82	1.92
SO_3	2.73	0.49
K_2O	0.92	1.89
Na_2O	0.22	0.58
Loss on ignition	3.02	1.78
Physical properties		
Specific gravity	3.15	2.25
Specific surface area, m^2/kg	326	287

Table 2
Sieve analysis and physical properties of normal weight fine aggregate.

Sieve size (mm)	Fine aggregate	
	River sand	Crushed sand
Sieve analysis		
16.0	100	100
8.0	99.7	100
4.0	94.5	99.2
2.0	58.7	62.9
1.0	38.2	43.7
0.50	24.9	33.9
0.25	5.40	22.6
Fineness modulus	2.79	2.38
Physical properties		
Specific gravity	2.66	2.45
Absorption, %	0.55	0.92

concrete formulation, their characteristic material behavior as well as geometry, distribution, orientation and concentration of fibers [17,18].

Some researches indicated that the shrinkage of cementitious materials is reduced by the use of SRA [19–23]. This reduction of drying shrinkage of concrete containing SRA may be up to 50% [13,24,25]. It subsequently increases the age of cracking and reduces the corresponding crack width [26–28]. The addition of SRA also affects the strength properties and pore structure of concrete. The compressive strength of concrete containing SRA may be reduced by 10–25% [13]. This reduction however is highly dependent on the curing conditions [22]. Even 28% compressive strength reduction is reported compared to the that of the control concrete [29].

As far as the concrete containing steel fiber is concerned, the compressive strength is improved with an increase in fiber volume at each fiber aspect ratio [30]. This increase of compressive strength of concrete containing steel fiber may be up to 20% [31,32]. The splitting tensile strength however benefits better from the fiber-reinforcement which provides up to 98% improvements in terms of the increase in volume fraction of steel fiber [32]. Some researches indicated that the addition of fibers to the concrete influences the drying shrinkage minimal and helps in reducing the cracks formed due to restrained shrinkage [33,34].

It is known that utilization of polymeric or steel fibers has beneficial effect on the flexural capacity, toughness, post-failure ductility and crack control [35] as well as the compressive ductility, and energy absorption at early age [36]. The basic information on the mechanical properties of steel fiber-reinforced lightweight high-strength concrete has provided by Gao et al. [37] and Balendran et al. [15]. There are some recent studies indicating these beneficial effects on the mechanical properties of lightweight

Table 3
Concrete mix design.

Mix no.	Mix description	*w*/*c* Ratio	Mix proportions (kg/m^3)								Fresh density (kg/m^3)
			Cement	Water	SP	SRA	Steel fiber	LWCA	Fine aggregate		
									River sand	Crushed sand	
1	Plain	0.4	450	180	5.4	0	0	644	596.8	236.0	2153
2	0.75% SRA	0.4	450	180	5.4	3.38	0	641	592.4	234.2	2149
3	1.50% SRA	0.4	450	180	5.4	6.75	0	637	587.8	232.4	2144
4	3.00% SRA	0.4	450	180	5.4	13.5	0	631	594.3	235.0	2136
5	0.25% Steel fiber	0.4	450	180	9	0	19.625	641	587.9	232.4	2150
6	0.75% Steel fiber	0.4	450	180	10	0	58.875	640	587.6	232.3	2149
7	1.25% Steel fiber	0.4	450	180	12.4	0	98.125	638	584.9	231.3	2146