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Fracture behavior and mechanical properties of concrete with artificial lightweight aggregate and steel fiber

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HIGHLIGHTS

- Fly ash lightweight aggregate (LWA) were produced by using cold bonding process.
- LWA was used as coarse aggregate at two volume fraction in the concrete production.
- Effect of steel fiber aspect ratio and volume fraction on fracture properties were investigated.
- Fracture properties of the concrete were remarkably affected by using LWA and steel fiber.

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ABSTRACT

In this study, the mechanical and fracture properties of steel fiber (SF) reinforced cold bonded fly ash lightweight aggregate concretes (LWACs) were experimentally investigated. The LWACs were produced with constant water-to-cement ratio of 0.40 and two different volume fractions of lightweight coarse aggregates (LWCA). Three types of hooked-end SFs with aspect ratios of 55, 65, and 80 were utilized 0.35%, 0.70%, 1.00%, and 1.50% of concrete volume. Effectiveness of aspect ratio, SF volume fraction, and LWCA content on the compressive, splitting, and flexural strengths as well as the modulus of elasticity, fracture energy and characteristic length of the concrete were investigated at the end of 28-days of water curing. Test results revealed that the utilization of SF crucially enhanced the splitting tensile and flexural strengths, fracture energy and characteristic length. The compressive strength, however, were not affected considerably by SF addition. Moreover, the concrete properties mentioned above were significantly influenced by artificial fly ash LWCA content.

1. Introduction

Concrete with lightweight aggregates (LWAs) has been used successfully for structural purposes since the second half of the twentieth century. Expanded clay or shale, and sintered fly ash, which are the commercially available lightweight aggregates, are acquired through heat treatment at 1000–1200 °C [1]. An alternative way to produce lightweight aggregate is applying the cold-bonding process on the fly ash. Cold-bonding process is production of pellets in a tilted revolving pan with agglomeration of fly ash particles while using water as wetting agent and lime or Portland cement as binder. Production of artificial fly ash lightweight aggregates with cold-bonding process needs much less energy consumption when compared with sintering. Almost 15 million tonnes of fly ash is being generated from thermal coal-fired power plants annually in Turkey while a very small amount of it is being utilized in the construction industry [2]. Using the fly ash in the production of lightweight aggregates as well as decreases its damage to the environment. Lightweight concretes (LWCs) in the strength range of 30–80 MPa can easily be made [3–8] while by using such aggregates, LWCs with compressive strength ranging from 20 to 50 MPa may be practically produced [9–12].

Many countries like the UK, USA, Germany, Poland and Russia are producing the lightweight aggregates commercially under different trade names [13]. Many studies are conducted to investigate the engineering properties of concrete manufactured by the commercially produced lightweight aggregates [6,13–17]. The improvement in the properties of both fresh and hardened concrete, durability and its environmental impact are very important topics for researchers [18]. The utilization of fibers in concrete

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

Chemical analysis (%)	Portland cement	Fly ash
CaO	63.84	2.24
SiO_2	19.79	57.2
Al_2O_3	3.85	24.4
Fe_2O_3	4.15	7.1
MgO	3.22	2.4
SO_3	2.75	0.29
K_2O	-	3.37
Na_2O	-	0.38
Loss on ignition	0.87	1.52
Specific gravity	3.15	2.04
Fineness (cm^2/g)	3260*	3790*

- = Not measured items.
* Blaine specific surface area.

Table 2
Sieve analysis and physical properties of normal weight and lightweight aggregates.

Sieve size (mm)	Natural fine aggregate (%)	Lightweight coarse aggregate (%)
31.5	100	100
16.0	100	100
8.0	100	47.3
4.0	100	0
2.0	56.8	0
1.0	35.0	0
0.50	22.7	0
0.25	16.4	0
Specific gravity	2.42	1.71

enhances some engineering properties of concrete. The fibers can be made from either natural materials (asbestos, sisal and cellulose) or manufactured products (glass, steel, carbon and polymer) [19]. The most beneficial enhancement is conducted on the flexural capacity, toughness, post-failure ductility and crack control [20] as well as the compressive ductility, and energy absorption at early age [21]. Fibers can be classified as metallic, polymeric or natural [22]. Steel fiber is the most commonly used type among the various fibers for most structural and non-structural purposes [23,24]. The economics, manufacturing facilities, reinforcing effects and resistance to environmental aggressiveness are the reasons for larger usage of steel fiber [25]. Concrete is a brittle material having low tensile strength and shear capacity [26–28]. Concrete having a strength over 100 MPa can be produced by conventional mix design methods and ordinary materials [29]. Increasing the strength of concrete, however, decreases its ductility [30,31] and makes it very sensitive against cracking [18].

The properties of the steel fiber reinforced concrete are significantly affected by the type and volume fraction of steel fiber. Mehta [23] classified the fiber-reinforced composites as low, moderate and high fiber content concretes containing, respectively, less than 1%, between 1% and 2%, and with more than 2% of fiber volume. Dvorkin and Dvorkin [24] reported that the tensile, flexural and compressive strengths are increased by up to 100%, 150–200% and 10–25%, respectively, with the utilization of 1–1.5% of steel fiber in the concrete by volume. Moreover, the concrete transforms from a brittle to a more ductile material by the addition of steel fibers [32,33] and steel fiber concretes have much higher fracture energy than plain concrete [34]. Nevertheless, adding steel fibers into concrete has certain disadvantages. Workability may be reduced [35]; dead load of composite may be increased [36]; and mixing and placing time may be extended [37,38].

Table 3
Physical and mechanical properties of steel fibers.

Name of fiber	Length (L) (mm)	Diameter (d) (mm)	Aspect ratio (L/d)	Density (g/cm^3)	Tensile strength (N/mm^2)
Dramix 80/60	60	0.75	80	7.85	1050
Dramix 65/60	60	0.92	65	7.85	1160
Dramix ZP305	30	0.55	55	7.85	1345

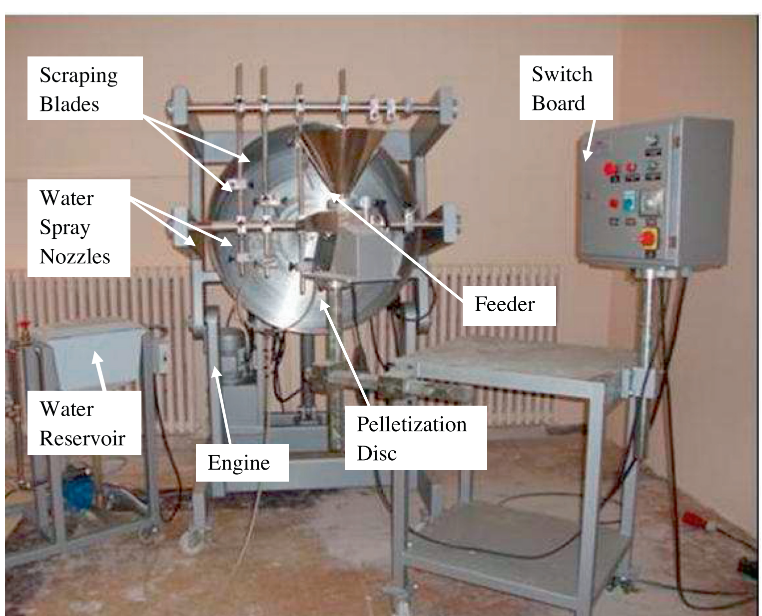

Fig. 1. The general view of the pelletization disk.