Construction and Building Materials 47 (2013) 358–365

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Effect of steel fiber addition and aspect ratio on bond strength of cold-bonded fly ash lightweight aggregate concretes

Erhan Güneyisi *, Mehmet Gesoğlu, Süleyman İpek

Department of Civil Engineering, Gaziantep University, 27310 Gaziantep, Turkey

HIGHLIGHTS

- Fly ash lightweight aggregate (LWA) were produced using cold bonding process.
- LWA were utilized with two volume fractions as coarse aggregate.
- Effect of volume fraction and aspect ratio of steel fiber on bond strength was studied.
- Utilization of steel fiber significantly increased the bond strength.

ARTICLE INFO

Article history:
Received 9 January 2013
Received in revised form 26 March 2013
Accepted 4 May 2013

Keywords:
Aspect ratio
Bond strength
Cold bonding
Lightweight fly ash aggregate
Modeling
Steel fiber

ABSTRACT

In this study, the adherence between reinforcing steel bar and the cold bonded fly ash lightweight aggregate concretes (LWAC) with and without steel fiber were evaluated by means of bond strength test. The concretes dealt with this study were produced by two different cold bonding fly ash lightweight coarse aggregate contents. The LWAC with constant water-to-cement ratio of 0.4 and 400 kg/m^3 cement content were designed. Three types of hooked-end steel fibers with the aspect ratios of 55, 65, and 80 were utilized with four different volume fractions of 0.35%, 0.70%, 1.00%, and 1.50% of concrete volume. The effectiveness of aspect ratio, steel fiber volume fraction, and lightweight aggregate content on the bond strength were investigated at the end of 28-days of water curing. Analyses of variance on the experimental data were performed and the levels of the significance of the lightweight aggregate content, steel fiber aspect ratio and volume fraction on the bond strength of the concretes were evaluated through general linear model analysis of variance (GLM-ANOVA). Furthermore, a mathematical model was proposed for predicting the bond strength of the concretes dealt with the current study. The results revealed that utilization of steel fiber enhanced the bond strength and the ductility of pull-out failure. Moreover, the bond strength was significantly affected by the artificial fly ash lightweight aggregate content.

1. Introduction

Concrete with lightweight aggregates (LWAs) has been used successfully for structural purposes since the second half of the twentieth century, and became a very proper alternative when compared with conventional concrete. 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]. Increasing use of lightweight concrete (LWC) brought the need for the artificial lightweight aggregate production which may be achieved by cold bonding manufacturing process, where the water is the wetting agent acting as coagulant and the lime or Portland cement is the binder, so that the moist mixture would be pelletized in a tilted revolving pan. Production of artificial fly ash lightweight aggregates with cold-bonding process needs much less energy consumption when compared with sintering. Moreover, using fly ash in the production of lightweight aggregates decreases the environmental damage of it.

LWC in the strength range of 30–80 MPa can easily be made [2–7], while by using such aggregates, LWC with compressive strength ranging from 20 to 50 MPa may be practically produced [8–11]. The compressive strength, however, is not the only major concept for the structural concretes. The convenient adherence between reinforcing bars and concrete is the most desired property due to dependence of structural performance of reinforced concrete members on the monolithic behavior. Quality of concrete significantly affects the bond occurring between the steel bars and concrete. The improvement of the bond between steel bar and concrete always attracts the attention of the researchers. Many studies are conducted to investigate adherence between steel bar and the conventional concrete. Some pozzolanic materials, such

* Corresponding author. Tel.: +90 342 3172426; fax: +90 342 3601107.
E-mail address: guneyisi@gantep.edu.tr (E. Güneyisi).

0950-0618/$ - see front matter
http://dx.doi.org/10.1016/j.conbuildmat.2013.05.059

as silica fume, fly ash and metakaolin, were used to acquire the high performance concrete [12,13]. These materials supply additional performance to the concrete through reacting with Portland cement hydration products to form secondary C–S–H gel, the part of the paste mainly responsible for concrete strength [12]. Utilization of pozzolanic materials as an additional or replacement material into concrete is a method to enhance the engineering properties of concrete, such as fracture energy, characteristic length, and compressive, bond, splitting tensile and flexural strength.

The fiber addition into concrete is another method to enhance these engineering properties of concrete. The most beneficial enhancement is conducted on the flexural capacity, toughness, post-failure ductility and crack control [14] as well as the compressive ductility, and energy absorption at early age [15]. Fibers can be classified as metallic, polymeric or natural [16]. The fiber can be made from either natural material (asbestos, sisal and cellulose) or a manufactured product (glass, steel, carbon and polymer). Steel fiber is the most commonly used type among the various fibers for most structural and non-structural purposes [17,18]. The economics, manufacturing facilities, reinforcing effects and resistance to environmental aggressiveness are the reasons for larger usage of steel fiber [19]. The steel fiber concentration, orientation and distribution as well as geometry influence the characteristics and performance of the concrete. Dvorkin and Dvorkin [18] reported that the tensile strength of steel fiber concretes is increased by up to 100%, flexural strength of them is increased by up to 150–200% and compressive strength by up to 10–25% with the utilization of 1–1.5% of steel fiber in the concrete by volume. Gesoğlu et al. [20] revealed that addition of steel fibers indicated remarkable improvement in bond strength of investigated concretes. Moreover, the concrete transforms from a brittle to a more ductile material by the addition of steel fibers [21,22] and steel fiber concretes have much higher fracture energy than plain concrete [23].

In this study, effectiveness of volume fraction and aspect ratio of steel fiber as well as LWA content on the adherence between reinforcing steel bar and concretes was investigated through an experimental program. The adherence between steel bar and concrete was determined in terms of bond strength at the end of 28 days of water curing. The concretes were produced by two different cold bonded fly ash lightweight aggregate volume fractions (V_a) of 45% and 60% at constant cement content and water-to-cement ratio. The steel fiber with three different aspect ratios (L/d) of 55, 65, and 80 were utilized with four different volume fraction (V_f) of 0.35%, 0.70%, 1.00% and 1.50% as an additional. The statistical analysis and calculation of the contributions of lightweight aggregate content, steel fiber aspect ratio and volume fraction on the rebar-concrete bond strength were realized by general linear model analysis of variance (GLM-ANOVA). Moreover, an empirical model for predicting the bond strength of steel fiber reinforced LWACs was generated. The parameters used in this model were lightweight fly ash aggregate volume fraction (V_a), steel fiber volume fraction (V_f), steel fiber aspect ratio (L/d), compressive and splitting tensile strength of concretes.

2. Experimental study

2.1. Materials

Ordinary Portland cement (CEM I 42.5R) with specific gravity of 3.15 g/cm^3 and Blaine fineness of 326 m^2/kg was utilized in this study. It was used in the production of both artificial lightweight aggregates and concretes. Class F fly ash (FA) according to ASTM C 618 [24] with a specific gravity of 2.04 g/cm^3 and Blaine fineness of 379 m^2/kg was utilized in the manufacturing of cold bonded fly ash lightweight aggregates which was supplied from Çatalağzı Thermal Power Plant, Zonguldak, Turkey. Physical properties and chemical compositions of the cement and fly ash are given in Table 1.

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 (m^2/kg)	326[a]	379[a]

[a] 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 (g/cm^3)	2.42	1.71

Fine aggregate was crushed limestone sand. It was obtained from the local source. Properties of the fine aggregates are presented in Table 2. Sulphonated naphthalene formaldehyde based high range water-reducing admixture with specific gravity of 1.22 was employed to achieve target slump value for the ease of handling, placing, and consolidation in all concrete mixtures. The superplasticizer was adjusted at the time of mixing to achieve the specified slump.

Three types of commercially available hooked end steel fibers (Dramix ZP305, Dramix 65/60, and Dramix 60/80) were used for production of steel fiber reinforced concretes. The physical and mechanical properties and aspect ratios of the steel fibers are given in Table 3.

2.2. Artificial fly ash aggregates

In the first stage of the experimental study, artificial lightweight fly ash aggregates utilized in the concrete production were produced through the cold bonding agglomeration process of fly ash (FA) and Portland cement (PC) in a tilted pan at an ambient temperature. For that reason, a dry powder form of 10% Portland cement and 90% class F fly ash were mixed in the pelletizer as shown in Fig. 1a. A pelletizer with a pan diameter of 800 mm and a depth of 350 mm was used for producing the fly ash pellets. The total pelletization time of a typical production was determined as 20 min. During the first 10 min of the manufacturing, the water was sprayed onto the dry powder mixture of fly ash-cement to act as coagulant. The amount of sprayed water was determined as 22% of the material by weight. The pelletizer disc was continued to rotate in the second half of the agglomeration to obtain compacted and stiff spherical fresh pellets as shown in Fig. 1b. Afterwards, fresh pellets were maintained in plastic bags and stored for 28 days in a curing room in which the temperature and the relative humidity were 20 °C and 70% [25], respectively. At the end of the curing period, hardened aggregates were sieved. The coarse aggregates used in the concrete production were obtained from passing a 12-mm sieve and retained on 4-mm sieve. Specific gravity test of the saturated surface dry

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