Construction and Building Materials 123 (2016) 508–515

Contents lists available at ScienceDirect

Construction and Building Materials

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

Effects of maximum aggregate size on fracture behaviors of self-compacting lightweight concrete

Mohammad Karamloo [a], Moosa Mazloom [a,*], Gholamhasan Payganeh [b]

[a] Department of Civil Engineering, Shahid Rajaee Teacher Training University, Lavizan, Tehran, Iran
[b] Department of Mechanical Engineering, Shahid Rajaee Teacher Training University, Lavizan, Tehran, Iran

HIGHLIGHTS

- Fracture parameters of SCLC were obtained by SEM.
- As the maximum aggregate size increased, fracture energy increased.
- SCLC members must be designed by nonlinear fracture mechanics.
- Size effect law can predict failure loads of SCLC members with good precision.
- Brittleness of specimens is affected by w/c ratio and maximum size of aggregate.

ARTICLE INFO

Article history:
Received 22 April 2016
Received in revised form 24 June 2016
Accepted 15 July 2016

Keywords:
Self-compacting lightweight concrete
Fracture parameters
Coarse aggregate
Fracture energy
Size effect method
Mechanical properties

ABSTRACT

This study considers the influences of maximum aggregate size (d_{max}) on fracture parameters and brittleness of self-compacting lightweight concrete. A series of three point bending tests were carried out on 84 notched beams with different sizes. Six compositions with d_{max} = 9.5, 12.5 and 19 mm, and water/cement ratios of 0.35 and 0.4 were considered. In each mix, the parameters were analyzed by size effect method. The results indicated that as d_{max} increased, the fracture toughness and energy increased, which may be explained by changes in fractal dimensions. Moreover, the ductility, measured by means of effective length of fracture process zone, increased.

1. Introduction

Structural self-compacting lightweight concrete (SCLC) is a new generation of concrete in which lightweight coarse aggregate and normal fine aggregate are embedded into highly flowable paste. SCLC can be defined as concrete with the ability to fill the complex formworks and flow through congested reinforcing without bleeding and segregation [1]. This generation of concrete mixes can also offer safer construction, economical, technical and environmental advantages attributed to self-compacting concrete mixes such as reducing the noise emission and enhancing the speed of construction [2]. Besides, SCLC suggests cleaner environment due to use of ultra-fine particles such as lime stone powder and lower effective weight in structures, which permits larger spans and causes reduction in member's dimensions.

Apart from the mentioned advantages, the use of high amounts of ultra-fine particles, different type of coarse aggregate, and powerful plasticisers, may raise some concerns among researchers about the differences between the behavior of normal concrete (NC), self-compacting concrete (SCC), and lightweight aggregate concrete (LWAC). These differences in mixing parameters may lead to changes in the cracking pattern, and consequently mechanical and fracture behavior of SCLC compared to NC, LWAC and SCC.

Fracture energy is one of the most important parameters describing fracture behavior of concrete [3]. In composite materials, constituents and interactions between them play an important role in global behavior of material. In this regard, many researches have been conducted all over the world to clarify the effects of aggregate content, cement paste volume, additives, admixtures, ultra-fine particles and micro structure of concrete on fracture properties and cracking pattern of concrete [2–8].

---

* Corresponding author.
E-mail addresses: m.karamloo@srttu.edu (M. Karamloo), mazloom@srttu.edu (M. Mazloom), g.payganeh@srttu.edu (G. Payganeh).

http://dx.doi.org/10.1016/j.conbuildmat.2016.07.061
0950-0618/

Alyhya et al. [3] reported that in self-compacting concrete (SCC), larger coarse aggregate made fracture energy larger. Beygi et al. [2,5] stated that in SCC as the volume and size of coarse aggregate increased, fracture energy and length of fracture process zone increased. They also investigated the effect of water to cement ratio on fracture parameters and brittleness of SCC and reported that with decrease of w/c ratio from 0.7 to 0.35, fracture toughness and brittleness number increased [9]. Nikbin et al. [4] investigated the influence of powder content on the fracture behavior of SCC and reported that the increase of the mineral filler content caused the fracture energy to increase slightly and to approach brittle behavior. On normal concrete (NC), effect of aggregate content on fracture parameters has been considered [10]. Their test results indicated that as the volume fraction of aggregate increased, the size of fracture process zone decreased.

Interfacial transition zone (ITZ) is the weakest link of NC [11], so the cracking path is affected by the properties of this phase in normal concrete. Researchers reported that the properties of ITZ are mainly influenced by the properties of aggregate such as size, volume, shape, surface, and texture [12–15]. On the other hand, Zanjani zadeh [16] stated that in lightweight concrete containing fly ash and granulated blast-furnace slag, mechanical properties of ITZ, because of internal curing caused by lightweight aggregate, were very similar to bulk paste. Scanning electron microscope scans showed that shape and texture of particles and their water absorption would seriously affect the micro level interaction between the aggregate and surrounding cement paste [17]. Wasserman [18] reported that higher absorption of lightweight aggregate could cause concrete of higher strength due to denser ITZ. Besides, internal curing, caused by water absorption of LWA, reduces autogenous shrinkage (which is one of the important sources of cracking in concrete) by decreasing the effect of self-desiccation [19–21]. Instead, it might increase drying shrinkage of concrete [22]. Nevertheless, in self-compacting lightweight concrete, strength of LWA is the other key parameter, which can affect the cracking path. Tang [8] claimed that in a same mix composition, beside the same specific fracture energy, fracture toughness of the lightweight aggregate concrete (LWAC) was considerably lower than NC.

Strength of aggregate, ITZ characteristics, autogenous and drying shrinkage, are of main parameters affecting the cracking pattern and consequently fracture behavior of concrete. There are many researches in the literature about the fracture parameters of NC. In recent years, as mentioned earlier, researchers paid more attention to fracture behavior of SCC, but besides all advantages of SCLC, researches in this respect were too rare. In this regard, due to lack of knowledge about the fracture behavior of SCLC, the use of existing design equations, which are valid for other types of concrete, might be somehow risky.

This paper describes an experimental investigation on effects of maximum coarse aggregate size on fracture parameters of SCLC using size effect method (SEM). In order to do so, tests have been carried out on notched beam specimens according to RILEM recommendations [23]. In addition, other main mechanical parameters such as modulus of elasticity, tensile and compressive strength, have been determined.

2. Fracture parameters determination

2.1. Size effect method (SEM)

By using effective elastic crack model proposed by Bazant and Pfeiffer [24], SEM has been developed and included in RILEM TC-89 [23]. In this method, main fracture parameters such as fracture energy (G_f), length of fracture process zone (C_f), brittleness number (β), fracture toughness (K_{IC}), and crack-tip opening displacement ($CTOD_C$) are determined using 3-point bending test on notched beams with varying sizes. According to RILEM TC-89 [23], the size of specimen is determined regarding maximum aggregate size (d_{max}). Dimensions of specimens are shown in Table 1 and the used notations are illustrated in Fig. 1.

Table 1
Dimensions of beam specimens in SEM.

d_{max} (mm)	d (mm)	b (mm)	a_0/d	S/d	L/d
9.5	28.5	28.5	0.2	2.5	2.67
	57.1				
	114.3				
	228.6				
12.5	38.1	38.1	0.2	2.5	2.67
	76.2				
	152.4				
	304.8				
19	57.1	57.1	0.2	2.5	2.67
	114.3				
	228.6				
	457.2				

In this method by using extrapolation, the specific fracture energy, required for the growth of crack in an infinitely large test specimen, is obtained. In order to do so, five steps should be taken.

Step 1: Weight compensation to determine the corrected peak load P^0.

$$P_j^0 = P_j + \frac{2S_j - L_j}{2S_j} m_j g \quad j = 1, \ldots, n \tag{1}$$

where S and L are depicted in Fig. 1 and m is the specimen mass and g is gravitational acceleration.

Step 2: Linear regression considering the plot of the ordinates Y_j against the abscissae X_j where:

$$X_j = d_j, \quad Y_j = \left(\frac{bd_j}{P_j^0}\right)^2 \tag{2}$$

$$Y = AX + C \tag{3}$$

Step 3: Calculation of non-dimensional energy release rate using extrapolation functions, which depends on geometry of specimen.

$$g(\alpha) = 2.25\pi\left(\frac{S}{d}F(\alpha)\right)^2 \tag{4}$$

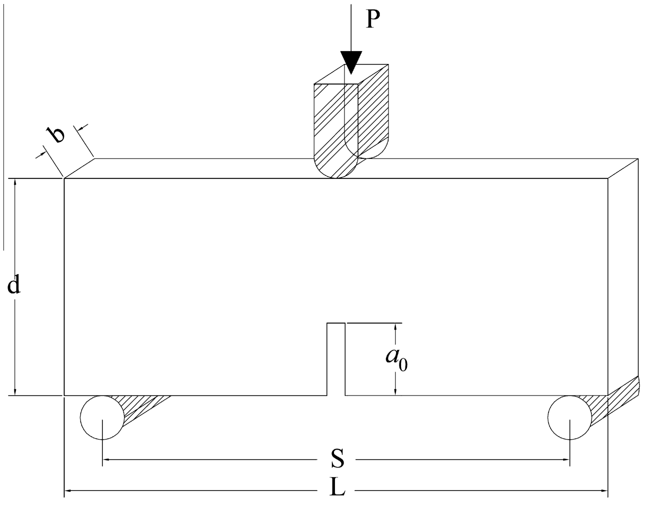

Fig. 1. Schematic 3-point bending test configuration.