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Influences of water to cement ratio on brittleness and fracture parameters of self-compacting lightweight concrete

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ABSTRACT

This paper discusses the effects of water/cement ratio on mechanical properties and fracture behavior of self-compacting lightweight concrete. For this purpose, four mix compositions with different water/cement ratios from 0.35 to 0.5 were prepared such that the nominal maximum aggregate size and weight of coarse and fine aggregates were kept constant. To determine the fracture parameters, twelve notched beam specimens were casted for each mix and the results were analyzed by means of the size effect method. The obtained results indicated that there is a remarkable relationship between the water/cement ratio, fracture behavior, and mechanical properties of this material.

1. Introduction

Concrete is a quasi-brittle material with nonlinear response exhibition even before cracking [1]. In order to explain the effects of cracking on concrete members, fracture parameters such as fracture toughness (K_{IC}), fracture energy (G_f), length of fracture process zone (C_f), and critical crack-tip opening displacement ($CTOD_C$) should be determined [2]. Although some references represent empirical relations for determination of fracture parameters [3], there are still debates on the issue of fracture behavior [1], which can be attributed to the remarkable influences of constituents, water/cement ratio, and size dependency of fracture behavior [4]. In this regard, many researchers considered the influences of mixing parameters such as water/cement ratio, maximum aggregate size, and coarse aggregate volume on fracture behavior of normal concrete (NC). For instance, Wittman et al. reported that as the water/cement ratio increased, the fracture energy decreased [5]. Prokopski et al. [4] considered the effect of water/cement ratio on the fracture toughness of gravel concrete and claimed that the increase of water/cement ratio increased the porosity of interfacial transition zone (ITZ) and lowered the K_{IC}. Prokopski observed that when the water/cement ratio of NC was within a range of 0.55–0.7, micro-cracks propagated inter-granularly along the grains of C_3S. But as this ratio increased to 0.9, in addition to the apparent increased porosity, the micro-cracks propagated trans-granularly in $Ca(OH)_2$ crystals [6]. Moreover, it is reported that the increase of water/cement ratio, decreased the mode-II fracture energy [6]. Petersson [7] reported that the fracture energy is highly affected by water/cement ratio. Ince et al. [8] investigated the effect of water/cement ratio based on two parameter model introduced by Jenq and Shah [9]. They claimed that by increasing the water/cement ratio, fracture toughness and critical crack-tip opening displacement decreased. Instead, Naus and Lott have claimed that there were no dependency between fracture

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Nomenclature

Latin

a	crack length
a_0	notch length
A	slope of fitted line
b	width of beam specimen
B	empirical parameter
C	intercept of fitted line
C_n	coefficient introduced for convenience
C_f	effective length of fracture process zone
d	depth of beam specimen
df	degrees of freedom
d_0	empirical parameter
E	modulus of elasticity
f_c	cubic compressive strength
f'_c	cylindrical compressive strength
f_t	tensile strength
g	gravitational acceleration
G_f	initial fracture energy
$g_f(\alpha_0)$	non-dimensional energy release rate
K_{IC}	fracture toughness
L	length of beam specimen
m	width of scattering band
m_0	mass of specimen
P	applied load
P^0	corrected peak load
S	span

Greek

α_0	initial notch/depth ratio
β	brittleness number
λ	lightweight aggregate modification factor
ω_A	coefficient of variation of slope
ω_C	coefficient of variation of intercept
σ_n	nominal failure stress

Acronyms

$CTOD_C$	critical crack-tip opening displacement
ITZ	interfacial transition zone
LWAC	lightweight aggregate concrete
MS	mean squares
NC	normal concrete
SCC	self-compacting concrete
SCLC	self-compacting lightweight concrete
SS	sum of squares

toughness of NC and its water/cement ratio. They further reported that this dependency was only observed in cement paste specimens [10]. Carpinteri et al. [11] observed that the fracture energy has its peak value in w/c = 0.65 within the range of 0.45–0.75.

During the past few decades, self-compacting concrete (SCC) has experienced major development in research phase and practical aspects. In this regard, by increasing the application of this category of concrete mixes, more attention has been paid to its fracture behavior in recent years [12–15]. Beygi et al. [16] considered the effect of water/cement ratio on fracture behavior of SCC and reported that as the water/cement ratio decreased, the fracture energy increased. Zhao et al. investigated the fracture behavior of SCC with different strength levels and claimed that the observed toughness values for SCC were lower than that of NC [17]. Some researchers considered the effects of filler contents on fracture parameters of SCC [12]. They reported that increasing the volume of filler content increased the fracture energy slightly. It is also reported that increasing

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