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Uniaxial bond stress-slip behavior of reinforcing bars embedded in lightweight aggregate concrete

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ABSTRACT

This paper presents an experimental study of bond-slip behavior of reinforced lightweight aggregate concrete (LC) and normal weight concrete (NC) with embedded steel bar. Tests were conducted on tension-pull specimens that had cross-sectional dimension with a reinforcing bar embedded in the center section. The experimental variables include concrete strength (20, 40, and 60 MPa) and coarse aggregate type (normal-weight aggregate and reservoir sludge lightweight aggregate). The test results show that as concrete compressive strength increased, the magnitudes of the slip of the LC specimens were greater than those of the NC specimens. Moreover, the bond strength and stiffness approaches zero at the loaded end, or close to the central anchored point of the specimen. In addition, the proposed bond stress-slip equation can effectively estimate the behavior of bond stress and steel bar slipping.

1. INTRODUCTION

Concrete has been described as the essential construction material because of its inherent material properties. However, normal-weight concrete (NC) made with Portland cement and conventional natural aggregate suffers from several defects, such as low tensile strength, less ductile, etc. Fortunately, with the advancement of concrete technology, various attempts to overcome these defects have resulted in the development of special concretes. For instance, lightweight aggregate concrete (LC) is made with lightweight cellular aggregates to replace traditional normal-weight aggregates. Compared with NC, LC possesses many advantages, such as higher strength/weight ratio, lower thermal conductivity, greater durability, and better seismic resistance and fire performance (Somayaji 2001).

The performance of reinforced concrete (RC) structures depends on adequate bond strength between concrete and reinforcing steel (ACI Committee 408 2003). In a RC flexural member, the bending stiffness along the length of the member will vary

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after cracking. In a cracked RC flexural member, the bending stiffness varies from a minimum value at the location of the crack to a maximum value midway between cracks. Owing to the bond transfer between concrete and reinforcing bars, the intact concrete between adjacent cracks is capable of resisting some tensile stress and thus contributing to the stiffness of the RC member. The contribution of the intact concrete in the tension zone is often referred to as tension stiffening effect (Zant and Byung 1984).

The stiffness of RC members has a significant effect on load distribution through the structure, and can have a major influence on the cracking and deflection of concrete structures. For accurate assessment of deflection in cracked RC members, tension stiffening effect must be considered in the calculation. International concrete code provisions such as Eurocode 2 (EC2 1993), CEB-FIP model code (CEB 2010) and ACI 318 Code (ACI Committee 318 2014) adopt similar approaches to take in to account the tension stiffening effect. These methods are based on the assumption of perfect bond between concrete and reinforcing bars. However, the bond properties such as bond strength, peak slip and the bond stress-slip relationship of LWC varied greatly from one research to another (Kankam 1997, Husem 2003, Demir and Husem 2015, Mo et al. 2015, Shaikh et al. 2016). Moreover, different investigators obtain even contradictory results. The significant variations in the bond properties reported by investigators were due to the difference in the bond test methods adopted or type of aggregate used for each investigation (Mo et al. 2016).

Numerous studies dealing with mechanical properties have shown that significant differences exist between LC and NC (Husem 2003, Basche et al. 2007, Tang et al. 2009, Chen et al. 2011a, Chen et al. 2011b, Tang 2015, Grabois et al. 2016). The failure mechanism of LC can differ significantly from NC and depend upon the type of aggregates used and its characteristics. In spite of the increasing use and demand for LC, there is still a lack of adequate explanations to understand the mechanisms responsible for the mechanical properties of LC. In particular, the bond stress-slip relationship in reinforced LC was quite complicated and not yet clearly understood. Therefore, this study aims to investigate the uniaxial bond stress-slip behavior of reinforcing bars embedded in lightweight aggregate concrete.

2. EXPERIMENTAL DETAILS

2.1 Materials and mix proportions

In this study, the materials used for the preparation of the samples included cement, silica fume, fine and coarse aggregates, superplasticizer, and reinforcing steel. Local ordinary Portland cement (OPC) with a specific gravity of 3.15 and a fineness of 3400 cm2/g complying with ASTM C150/C150M (ASTM C150/C150M-15 2015) was used. The silica fume was imported from abroad with a specific gravity of 2.08. Well-graded aggregate and washed natural sand were selected in accordance with ASTM C33/C33M (ASTM C33/C33M-13 2013). The fine aggregate was natural river sand and the normal-weight coarse aggregate was crushed stone with a maximum particle size of 19 mm. Their physical properties are listed in Table 1. The coarse LWA used in this study was locally produced from reservoir sludge. Its physical and mechanical properties are listed in Table 2. Two different superplasticizers (HICON HPC 1000 for