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Original article

Bond behavior of steel bars embedded in concretes made with natural lightweight aggregates

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A R T I C L E I N F O

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A B S T R A C T

The bond properties of reinforcing steel bars embedded in structural concrete made with locally available natural lightweight aggregates, was studied using pull-out tests on cubic specimens of 150 × 150 × 150 mm. A series of 30 specimens were cast considering the effect of bar diameter, and concrete compressive strength. Test results showed that the load-slip behavior of the structural lightweight concretes (SLWCs) investigated compare reasonably well with the behavior of concretes reported in the literature, and is dependent upon the compressive strength, bar size and the embedded length. The bond strength of SLWCs increased with a higher concrete compression strength but decreased as the bar diameter was increased. Comparisons of measured bond strength with the ACI bond equations showed that for all cases the experimental bond strength values were higher than the design ones. However, the results indicate use of caution when applying bond formulas of normal weight concrete to lightweight concretes. Furthermore, this study has revealed that locally available natural lightweight aggregates could be considered as a promising, and cost effective material for designing reinforced concrete members.

1. Introduction

Lightweight concrete has established itself as a suitable construction material whenever savings in the dead-loads in structures and energy conservations are required, and whenever there is an abundance of natural lightweight aggregates. Some geological surveys indicated that Saudi Arabia possesses huge deposits of the volcanic scoria rocks shown in Fig. 1, which are not utilized effectively (Sabtan and Shehata, 2000; Moufti et al., 2000). They extend in north-south direction and cover an area of 180,000 km^2 distributed among separate lava fields called harrats. The estimated reserves of scoria in some of these harrats amount to 5 million m^3. Recent investigations confirmed that the scoria deposits can be used for producing structural lightweight concrete 25% lighter than normal weight concrete (Shannag et al., 2014; Charif et al., 2014). Scarcity of information on bond behavior of deformed steel bars embedded in structural lightweight concrete limited the acceptance of this material in construction industry.

Bond of reinforcing steel bars and concrete is a major characteristic of reinforced concrete. In structural concrete design, perfect bond between the reinforcing steel and concrete is assumed. The existence of the bond is the basic condition for concrete and steel to work together as a kind of composite material. Without bond, the rebar would not be able to resist any external load, and the RC beam would behave exactly like a plain concrete member does. For instance, this type of beam would fracture quickly under a small tensile load.

There is huge information on bond behavior between reinforcing bar and normal weight aggregate concrete available in the literature, and some model equations were developed by a number of researchers (Gjørv et al., 1990; Valcuende and Parra, 2009; Lundgren, 1999; Elfgren and Noghabai, 2002; Sancak et al., 2011; Mor, 1992; Orangun, 1967; Kayali and Yeomans, 2000; Hassan et al., 2010). They clarified the effect of the bar diameter, embedded length in concrete, concrete strength, cover thickness and crack spacing on the bond strength. (Sancak et al., 2011), reported lower bond strength for deformed bars in structural lightweight concrete (SLWC) as compared with that of normal weight aggregate concrete (NWAC). They also observed that at the ultimate load the slip of ribbed bars for both NWAC and SLWAC specimens was not very different. Field performance has demonstrated

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Fig. 1. Natural Lightweight Rocks used in this investigation.

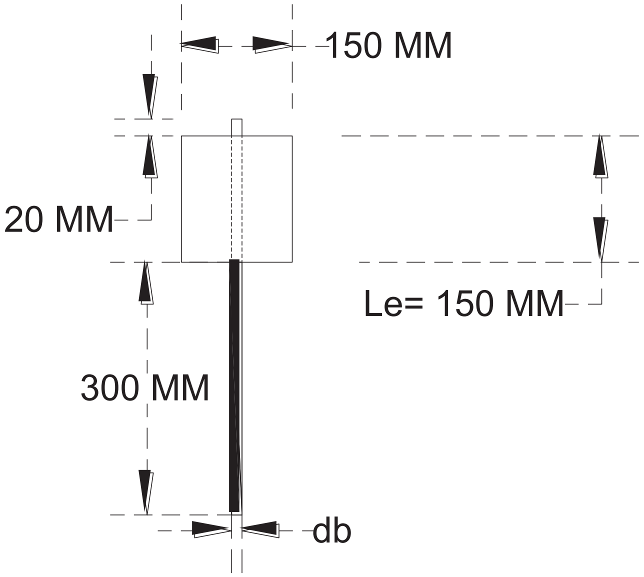

Fig. 2. Details of pull-out specimen.

satisfactory performance for bond and development length, of light density concrete (LDC) with concrete strength ranging from 20 to 35 MPa. The lower particle strength in LDC resulted in lower bond splitting strengths and reduced post-elastic straining as compared to normal density concrete (NDC). ACI 318-08 recommends a 1.3 increase factor for lightweight concrete compared to a factor of 1 for normal weight concrete (Holm and Bremner, 2000). Hossain (2008) reported lower bond strength of steel bars when used in volcanic pumice concrete (VPC) as compared to normal concrete (NC). NC specimens developed a normalized bond strength about 1.12 (ranging from 1.08 to 1.14) times that obtained with VPC counterparts. This lower bond strength for a lightweight concrete is understandable and the reduction is reasonable.

The bond behavior and strength between reinforcing steel bars and LWC is still not fully understood, and more research work on the bond characteristics of steel bars in lightweight aggregate concrete is required. Further research on bond behavior of LWC should contribute to the enhancement of existing code provisions for lightweight concrete. The main objective of this research is to investigate the bond behavior of reinforcing steel bars embedded in concrete made with locally available natural lightweight aggregates, using the pullout test setup presented in (ASTM C 234 specifications, 1991). The influence of matrix compressive strength and deformed steel bar size on bond strength is studied. Furthermore, the performance of the existing code provisions for predicting the bond strength of normal and lightweight concrete will be studied and compared with the data obtained from this investigation. This paper is part of a large scale research project aimed at investigating the possibility of producing structural lightweight concrete using locally available natural lightweight aggregates.

2. Experimental investigation

The experimental investigation was designed to study the influence of two main parameters on bond strength between steel bars and structural lightweight concrete: concrete strength and rebar diameter. A total of 30 pull-out specimens were cast using lightweight scoria aggregates. Two different concrete mixes were prepared namely M350, and M500 wherein the letter indicates Madina lightweight aggregates (LWA) and the numeral indicates the cement quantity. Deformed reinforcing bars having nominal diameters of 12, 14, 16, 20 and 25 mm were then embedded in each of the LW concrete mixes. Each concrete mix comprised of 15 specimens with 3 specimens each belonging to the five diameters of rebars. The details of the pull-out specimens are shown in Fig. 2. The cross-section of the pull-out specimens is square 150 mm × 150 mm and the embedment length of the bar is l_e = 150 mm. As it can be seen in Fig. 2, the steel rebar was embedded in the center of concrete with 300 mm of the rebar length projecting out on one end and 20 mm of the rebar on the other end. This was done to make sure that the measurements for rebar slip can be obtained and the rebar can be easily gripped for pull-out tests. Table 1 shows the test matrix used in this study. All pull-out specimens were tested at the end of 28 days after casting.

Table 1
Test-Matrix for pull-out specimens and properties of materials used.

Mix Designation	Embedment Length = 150 mm Rebar Diameter (mm)				
	12	14	16	20	25
	Number of Pull-out Specimens				
M350	3	3	3	3	3
M500	3	3	3	3	3
Total	6	6	6	6	6

Proportions of Concrete Mixes in (kg/m^3)

	Cement	Silica Fume	Water	LWCA	LWFA	Silica Sand	Superplasticizer
M350	350	40	240	450	400	240	8
M500	500	40	240	415	368	221	10

Properties of Concrete Mixes

Material Parameter	Compressive strength f'_c (MPa)	Air dry Unit weight (kg/m^3)	Modulus of Elasticity (MPa)	Slump
Mix M350	34	1860	15214	65
Mix M500	48	1925	20210	50

Properties of Steel rebars

Nominal Diameter	Yield Strength (MPa)	Ultimate strength (MPa)	Modulus of Elasticity (GPa)
12	428	668	192.4
14	430	667	196.5
16	425	686	201.2
20	423	708	202
25	424	686	196.4