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Review

Bond properties of lightweight concrete – A review

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HIGHLIGHTS

- Various factors influencing bond strength of LWC were reviewed and discussed.
- Bond strength, bond-slip relationship, peak slip and failure mode were summarized.
- Bond strength of LWC exceeds predicted value from codes of practices.
- Summary of bond equations proposed for LWC.

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ABSTRACT

The use of lightweight concrete (LWC) for structural application has attracted great interest due to its significant benefit in terms of design flexibility and overall costing. However, lack of information in terms of the structural performance such as the bond properties could be a hindrance to the application of LWC in the construction industry since insufficient reinforcement-concrete bonding could result in structural deficiency of reinforced concrete elements. Therefore, in order to establish the idea of using LWC as a more common construction material, this review details the bond performance of LWC, which includes lightweight aggregate concrete, foamed concrete and no-fines concrete and the various factors influencing their behaviour. The review also showed that generally the bond behaviour of LWC complied with bond requirements in codes of practice without the need for safety factors, and this could further enhance the feasibility of LWC for structural applications.

Contents

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1. Introduction

Bond is an important structural property of reinforced concrete and it refers to the adhesion between reinforcing bar and the surrounding concrete [1]. The bond between the reinforcing bar and concrete is required to allow reinforced concrete to behave as a composite structural material. Effective beam action required in codes of practice cannot be achieved if there is insufficient bond strength and this could render design equations to be invalid [2]. The loss of strain compatibility between reinforcing bar and concrete results in redistribution of stresses in reinforced concrete elements; this may cause excessive deflections and affect the load-carrying capacities of reinforced concrete members.

The bond force is transferred by two kinds of actions, physiochemical (adhesion) and mechanical (friction and bearing action), which are activated by various states of stress. These actions primarily depends on the surface texture and geometry of the reinforcing bars [3]. The adhesion force refers to the bonding between reinforcing bar and concrete; friction force arises from roughness of the interface, forces transverse to reinforcing bar surface and relative slip between reinforcing bar and concrete; bearing action is due to the mechanical anchorage of the ribs against concrete surface [4]. The adhesion, friction and bearing component of forces for a deformed reinforcing bar are illustrated in Fig. 1.

The type of concrete used also influences the bond behaviour since different types of concrete involves distinctive concrete mixture designs. For instance, in self-compacting concrete (SCC), researchers [5–7] reported higher bond strength compared to conventional concrete (CC) and this was attributed to the low water-to-binder (w/b) ratio and high powder volume in SCC which could reduce bleed water [8]. Similarly, for recycled aggregate concrete, the bond strength was found to be higher than CC [1,9] and it was suggested that the superior bond strength was contributed by the internal curing action of the recycled aggregate [1].

Another commonly researched concrete bond behaviour is lightweight concrete (LWC) since the type of aggregate used and mix design adopted in LWC also significantly differs from those in CC. The knowledge of the bond behaviour of LWC could provide better insight on the feasibility of LWC structures and hence facilitate the acceptance of LWC into the construction industry. This is of particular interest since LWC garners great interest for structural applications due to the significant reduction in self-weight of the concrete, which could lead to savings in terms of construction and transportation costs, as well as allowing greater flexibility in structural designs, such as for longer span members, reduced member sizes etc. Besides that, the reduction of self-weight in LWC is preferred especially for structures built in seismic zones, where they are susceptible towards lateral forces during earthquakes. Generally, it is presumed that LWC possess inferior properties compared to CC and the same was taken for the bond properties as reflected in the safety factor adopted in ACI 318. The development of the safety factor in the code is, however, debatable since contrasting findings were reported with regard to the bond behaviour of LWC.

In order to throw light on to the bond performance of LWC, this paper focuses on the review of the bond behaviour of LWC, which includes lightweight aggregate (LWA) concrete (LWAC), aerated concrete and no-fines concrete. In this review, various factors affecting the bond properties such as bond strength, peak slip and the bond stress-slip relationship of LWC as well as the comparison of the findings with codes of practices regarding the bond performance were also summarized.

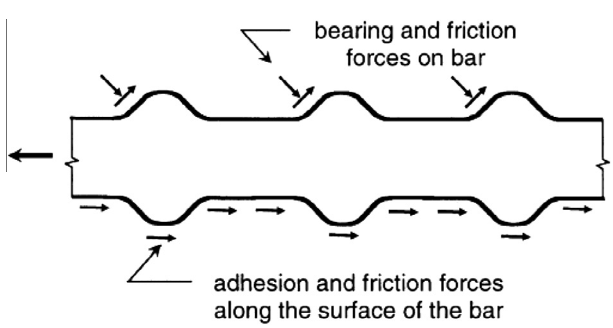

Fig. 1. Bond force transfer mechanism [4].

2. Bond properties of lightweight aggregate concrete

2.1. Bond strength

In the past, although most investigation of the bond properties of LWC dealt with LWAC, there were few studies which investigated the bond behaviour in no-fines concrete [10,11], aerated concrete [12–15] as well as semi-lightweight concrete [16,17]. In the investigation of LWC utilizing LWA, there were contradicting reports in terms of the bond strength in comparison with CC. Although it is generally assumed that bond strength of LWC to be lower than CC, there were also a number of findings which suggested higher bond strength of LWC [18–20]. In some cases, it was found that both LWC and CC had comparable bond strengths [21]. Table 1 summarizes the bond strength between LWC using different types of LWA and deformed steel reinforcing bars.

It could be observed that the bond strength of LWC varied greatly from one research to another, even when similar type of LWA was used. For instance, as shown in Table 1, in the case of LWC made with expanded clay aggregate, the range of bond strengths reported by Bogas et al. [20] were significantly higher than those obtained by other researchers; Wu et al. [30] and Mo et al. [44] found higher bond strengths compared to other researchers in the case of expanded shale and oil palm shell aggregate LWC, respectively. Such an occurrence could be attributed the pull-out failure mode observed in these studies as indicated in Table 1. It is also interesting to note that bond strengths of LWC found in recent times [19–21,30,45,49] were generally much higher, and within the range of about 15–20 MPa. The significant variations in the bond strength reported by researchers could also arise due to the difference in the bond test methods adopted for each investigation. Cairns and Plizzari [50] suggested that due to the absence of standard bond test method, the selection of different bond test method could cause scatter of results and impair