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Strength of bearing area and locking area of galvanized strips in foamed concrete

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HIGHLIGHTS

- Tensile capacity of embedded components significantly depends on the locking area.
- Increasing the number of holes provides a notable improvement in tensile capacity.
- Increase in locking area results in greater displacement at the initial stage.
- Extension of the holes to the upper edge causes failure of regional adhesion.

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ABSTRACT

Bond strength between the infill materials and embedded components of composite structural assemblies (CSAs) significantly affects the performance of sandwich panels. This paper presents the effectiveness of the interlocking area and bearing area on bond behaviour of galvanized steel strips as embedded components and foamed concrete as infill material. In total 60 pull-out specimens with a density of 1200 kg/m^3 were tested under tensile load. The specimens were prepared in two batches with different strip thickness. Each batch consists of ten groups with the variations on number of holes, locking holes area, bearing area, radius of holes, holes patterns and strips thickness. The results indicate that an increase in locking area results in higher tensile capacity along with greater displacement at the initial stage of loading due to lower interfacial area between strips and foamed concrete. Based on the experimental results equations were developed to analytically describe the bond slip behaviour, tensile capacity and bond strength of embedded steel strips in foamed concrete.

1. Introduction

Composite Structural Assemblies (CSAs) are products such as wall and roof panels which comprise of an embedded light gauge steel components and settable filler (such as lightweight concrete) along with coatings of film or sheet materials to provide a range of finishes (Fig. 1). The combination of these materials provides a superior performance in terms of strength and stiffness. However, the strength of a composite panel directly depends on grade and thickness of the embedded sheet materials along with the configuration of infill materials [1]. Generally, the structural performance of a composite system and its behaviour substantially depends on material characteristics and interaction between the components [1]. The interaction between the components of a matrix significantly relies on its bond strength. The degree of bond strength between the components of a composite matrix is attributed to a wide range of factors [2]. The literature contains many investigations about rebars embedded into concrete. The bond mechanisms of a composite matrix and its strength depend on the magnitude of shear stress generated by chemical adhesion, friction and mechanical interlocking between embedded rebar and matrix [3–5]. The resisting force associated with chemical adhesion breaks down at very small displacements between the embedded bar and surrounding concrete (0.48–1.03 MPa) [6]. The surface friction, which is up to 35% of resisting force [6,7], and mechanical interlocking between ribs and adjacent concrete keys are the main factors contributing to the resisting force [7]. Thus, the bond strength of a composite matrix is initially caused by the mechanical interlocking between the ribs and the concrete keys. At the ultimate stage, slippage occurs as shear cracks propagate at the interface zone of concrete and ribs as a result of large

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Nomenclature

A_c	bearing area (mm^2)	RD_s	relative density of sand
A_e	area of embedded region (mm^2)	R_h	radius of hole (mm)
A_h	area of holes (mm^2)	t_s	strip thickness (mm)
d_b	strip width (mm)	V_f	volume of foam (l)
f_y	yield strength of galvanized strip (MPa)	x	cement content (kg/m^3)
f_u	ultimate strength of galvanized strip (MPa)	a/c	ash-cement ratio
f'_c	compressive strength of foamed concrete (MPa)	s/c	sand-cement ratio
L_e	embedded length (mm)	w/a	water-ash ratio
L_L	length of locking zone (mm)	w/c	water-cement ratio
P_a	Adhesion bond stress (MPa)	w/s	water-sand ratio
P_i	Interlocking bond stress (MPa)	γ	concrete density (kg/m^3)
P_u	ultimate tensile capacity (MPa)	τ_u	ultimate average bond stress (MPa)
RD_a	relative density of ash	δ_a	actual density (kg/m^3)
RD_c	relative density of cement	δ_m	target casting density (kg/m^3)
RD_f	relative density of foam	δ_u	Maximum displacement at ultimate load (mm)

bearing stress around the ribs [8]. It has been confirmed that the concrete strength [6,9–13], steel strength, concrete cover thickness [3,10,11,14], transverse reinforcement, bar spacing [3,15], bar size [3], bar features [15–18], yield strength of embedded bar [3,9,13,19,20], bar casting position [21,22], confinement [23–26] and elastic and inelastic segment length [4,5] substantially affect the magnitude of the bond strength. The mechanical characteristics of concrete (compressive and tensile strength) affect the magnitude of bond stress as the development of micro cracks and transferring the shear force between the components of the matrix are attributed to the tensile stresses of concrete [10]. Moreover, increasing the compressive strength of concrete results in higher bond stress developed over the length of a spliced bar and affects the modes of bond failure [11]. Several equations are proposed by researchers to estimate bond stress at yield and ultimate stage [6,9,12,13,27]. The bond stress over the length of an embedded bar for concrete with a compressive strength lower than 55 MPa is the square root of its compressive strength ($f'^{1/2}_c$) [6], whereas the bond stress for unconfined and confined concrete higher than 55 MPa is $f'^{1/4}_c$ and $f'^{3/4}_c$, respectively [9,13]. The thickness of concrete significantly affects the bond stress due to the fact that a higher thickness is resulting in a higher confinement pressure [3]. The effects of embedded bar geometry [15], rib bearing area [17,18], and rib face angle [17] have been studied by several researchers [15,16]. The features of an embedded bar rib and its interlocking mechanism considerably affect the bond strength as a result of the significance of the mechanical interlocking on the bond strength [17,18]. Test results show that a reduction in rib face angle results in lower bond strength along with less concrete crushing at the interface of steel bar and surrounded concrete [15,17]. Confinement is a significant technique to enhance the bond strength of an embedded bar [4,5,23–26]. Other researchers show that increasing confinement pressure and controlling the spread of splitting cracks by transverse reinforcement [28], spiral reinforcement [29,30], shear bolts [4], aluminium tube [31,32], steel pipe [4,23,33–38], square hollow section [39], and fibre reinforced polymer (FRP) [5,40] significantly enhance the bond strength of embedded bar and changes the modes of failure [4,5,10,11,14]. Splitting and pull-out failure are two modes of bond failure [41]. The mode of failure changes from pull-out to splitting failure when the concrete cover and bar spacing is inadequate (i.e. insufficient confinement). In this case, cracks tend to propagate under the radial component of the rib bearing forces parallel to the embedded bar resulting in early bond failure [41]. The load-slip relation of concrete is a remarkable factor in the design of concrete structures and the understanding of the mechanism of bond and its parameters are significant. Pull-out, beam-end, beam anchorage and splice test are four types of standard tests for estimating the bond behaviour between the components of a composite matrix. The pull-out test is useful in assessing the load-slip relationship of reinforcing bars; however this method only applies a tensile load and does not reflect the state of stress in a composite matrix in use.

Foamed concrete can be produced by a pre-foaming method or mixed foaming method [42]. Mortar or cement paste foamed concrete (air-entraining concrete) is categorised as lightweight concrete due to the existence of larger amounts of homogeneous air-voids inside the matrix through a suitable foaming agent. This method causes high flowability, lower unit weight, minimal consumption of aggregate and excellent thermal insulation properties [43]. The factors such as foam agent specification, foam preparation method, material characteristics, mix design method, foam concrete production and its performance in fresh and hardened state are significantly important for the design of foamed concrete [43]. Increasing the early strength of foamed concrete along with a reduction on setting time is obtained by using calcium sulfoaluminate cement [44], high alumina cement [44], and rapid hardening Portland cement [45,46]. Substitution of fly ash (30–70%) [45,47–51] with ground granulated blast furnace slag (10–50%) [52,53] significantly reduces the hydration heat, cost and increases the consistency of the mixture, whereas silica fume (up to 10%) substantially improves the strength of foamed concrete [54,42,55]. The density and unit weight of foamed concrete was reduced by the addition of lime [46], oil palm shell [56], fly ash [57–59], chalk [60], crushed concrete [60], recycled glass [61],

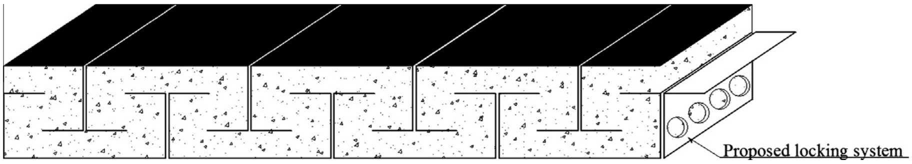

Fig. 1. Composite Structural Assemblies (CSAs) panel.