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Effect of bond layer thickness on behaviour of steel-concrete composite connections

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ABSTRACT

The performance of steel–concrete composite structural members depends on the connection at the steel–concrete interface. Structural adhesives are gaining rapid recognition as the bonding material between steel and concrete interfaces. The thickness of adhesive layer in a composite connection plays a key role in maximising the bond capacity. In this paper, the effect of the change in thickness of adhesive layer on the capacity of connection, ultimate slip at the interface, and the shear stiffness of connection have been studied. Twenty-five test specimens were cast and tested under direct shear to achieve the optimum thickness of adhesive layer. The ultimate strength and relative slip of all five adhesive layer thicknesses of steel–concrete specimens, obtained through experimental studies, were verified using finite element analysis. The failure patterns of bonded connection were also critically observed and found to be varying with adhesive layer thickness. It changes from adhesive failure to mixed (adhesive and cohesive) failure, and from mixed failure to cohesive mode of failure, with increasing thickness. At the optimum thickness, the composite interface experiences a mixed mode of failure. The effectiveness of bonded connections over mechanical shear stud connections was outlined through a comparison of the load-slip behaviour of both.

1. Introduction

Steel-concrete composite sections efficiently exploit the properties of concrete and steel, leading to stronger and economical members [1]. The primary requirement of a composite section is to effectively combine compression resistance of concrete with high tensile strength of steel, producing a member which is stiffer and stronger than a similar member of individual materials (as compared to non-composite section) [2]. Steel-concrete composite bridges are preferred over those made of other materials in the modern era. The connection between steel and concrete ensures appropriate transfer of forces between the two materials. The predominant forces acting on connections are the shear forces. To resist the shear force, interfacial shear connections are ensured generally either by mechanical shear connectors or an adhesive bond. Intermittently, the composite action at the interface may be ensured by adhesion, interlocking and friction [3]. Rigorous investigations for design and analysis of mechanical shear connections were carried out by numerous researchers [4–9] in the past. Studies are available in the literature on the application of rib shear connectors and perfobond rib shear connectors [10–12]. The pry out resistance of open rib shear connectors was presented by Classen and Hagger [10] and required minimum degree of shear connection for rib shear connectors was suggested by Classen [11]. An empirical expression was proposed by Su et al. [12] for the prediction of shear capacity of the perfobond shear connectors.

However, recently, the focus of researchers has shifted from mechanical shear connectors to adhesive bonding [2,13–21]. This shift can be attributed to certain advantages of adhesives over mechanical shear connectors. The adhesive bonding ensures uniform distribution of stress over bonded area and ease of application. The application of adhesive also allows the use of precast sections, leading to improved construction quality.

The bond strength of steel-concrete composite connections is a primary aspect for estimation of the capacity of the composite member. This bond strength, in turn depends on various factors such as individual mechanical and physical properties of adherends and adhesives, thicknesses of an adhesive layer etc. Failure due to deficient physical and mechanical properties can be eliminated by a careful selection of adhesives. Adherend surface conditions and bonding layer thickness are issues which require special attention.

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A number of studies are available in the literature for structural adhesive bonded metallic connections. Researchers express varying opinions about the effects of adhesive thickness on the strength of connections. Some researchers [22–24] reported that an increase in thickness leads to an increment in the connection strength; while some suggest the opposite [25–28]. Although these studies included interfacial connections between metal-metal, metal-composite and concrete elements. Silva et al. [23] conducted the experiments on lap joint metallic connection and reported that the thin layer of bonded adhesive fails at lower load due to the concentration of shear stresses at bond level. This can be attributed to the high strain at the bond line level. Derwonko et al. [22] reported that at same load levels, higher shear stresses were observed for lesser bond thickness. In cases of short bond length, brittle adhesive, high strength and thick adherends, the strength and failure mechanism of a composite member depends on the thickness of bonded connections [23], while, the traction-deformation relation is not affected by the thickness of an adherend [29]. The effects of increase in thicknesses of adhesive layer on fracture energy have also been studied by some researchers. Enhanced bond energy with an increase in thickness was reported by Martiny et al. [30]. Cooper et al. [31] reported that fracture energy increases with increase in thickness up to a certain point, beyond which the fracture energy remains almost constant. In another study, Carlberger and Stigh [32] reported that the fracture energy of the connections increases with an increase in the adhesive thickness up to a certain limit, beyond which the fracture energy decreases with a further increase in thickness. A similar pattern was also observed for both shear and peel mode of yielding.

A few studies on concrete bonded with FRP (Fibre Reinforced Polymer) have been published in recent years. Researchers [33,34] observed that the shear and peeling stresses in bonded adhesives at the end of bonded joints are affected by the adhesive thickness and failure modes. Another study carried out by Lopez-Gonzalez et al. [35], aimed at understanding the effect of the strength of an adherend on the mode of failure suggested that for specimens with low strength of concrete, irrespective of the thickness of adhesive's layer, failure generally occurs in concrete. However, for a specimen with high strength concrete, failure was reported at the level of epoxy concrete interface. This can be explained using the concept of the capacity of individual components or their interface [35,36]. Jurkiewiez et al. [20] and Cognard et al. [36] reported that increment of epoxy thickness in bonded assembly, generally decreases connection efficiency. Adhesive joints having less thickness show enhanced bond strength and very high connection rigidity [18,37]. Colak [27] studied the bond strength of steel rod bonded in concrete element subjected to pull out tests, and concluded that the connection bond strength increases up to a bond thickness of 2 mm and decreases beyond 2 mm. However, the investigations pertaining to variation of shear strength of steel-concrete composite connections (steel beam-concrete slab) with thickness of adhesive layer are not reported in any study.

In the present study, experimental investigations on adhesive bonded steel-concrete composite push out specimens were carried out. The testing scheme was designed to determine the effect of thickness of adhesive layer on the shear strength of connections, their failure mechanisms along with the individual stiffness of connections. The effectiveness of adhesive bonded connections and the connections with mechanical shear studs was also compared on the basis of their load-slip behaviour obtained through push out tests. A numerical study was conducted to verify the experimental results.

2. Push out test

Push out test is widely used to predict shear strength, force transfer mechanism, failure mode of connection and effective bond length. Ernst et al. [38] concluded that the behaviour of push out test specimen and full-scale beam are identical. They also concluded that the behaviour and performance of shear connection can be efficiently predicted using the results of push out tests.

2.1. General arrangement and methodology

An experimental programme was designed to evaluate the optimum bond thickness of connections using twenty-five push out test specimens. Five specimens with adhesive layer thickness of 1 mm, 2 mm, 3 mm, 4 mm and 5 mm were prepared to analyse the correlation between bond thickness and connection capacity. The primary purpose of each of the five specimens of adhesive layer thickness is to obtain a better estimate of strength and slip capacity of connections. Five layers of thicknesses provide an estimate of the failure modes of connection interfaces in the specimens. Three identical mechanical shear stud connected steel-concrete composite push out test specimen were prepared to compare the composite behaviour with bonded connection.

The geometrical arrangement for both (adhesive bonded and mechanical connected) push out test specimen were selected in accordance with Eurocode 4 [39]. The primary reason to adopt the geometry of double lap compressive shear test (Eurocode 4 [39] geometry) is to avoid the eccentricity in connection that can generally be observed in single lap shear test as suggested by ASTM D1002 [40]. The dimensional details for adhesive bonded composite specimen were adopted

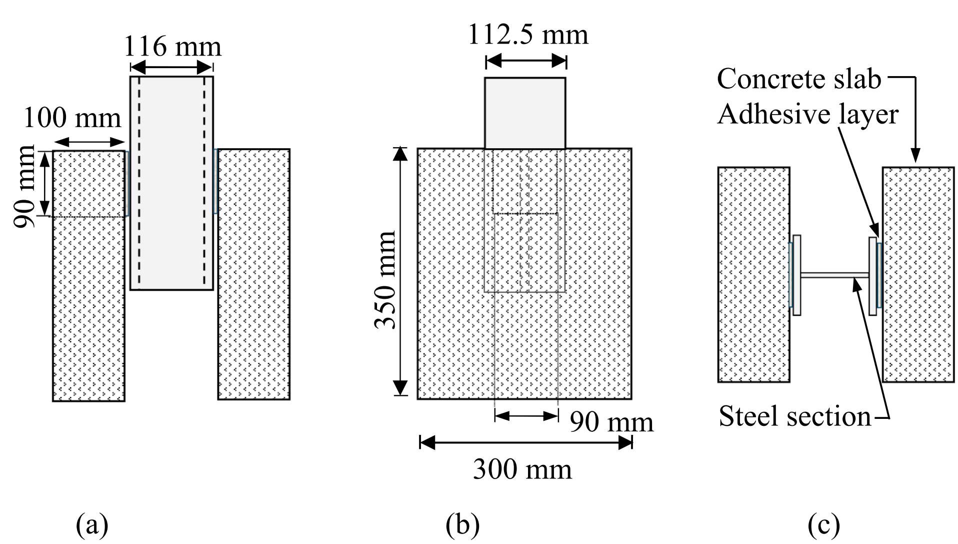

Fig. 1. Geometric detail of steel-concrete composite push-out test specimen bonded with structural adhesive; (a) front view, (b) side view, and (c) top view.