Engineering Failure Analysis 41 (2014) 124–134

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Fatigue energy dissipation and failure analysis of angle shear connectors embedded in high strength concrete

Mahdi Shariati *, Ali Shariati, N.H. Ramli Sulong, Meldi Suhatril, M.M. Arabnejad Khanouki

Department of Civil Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Available online 13 March 2014

Keywords:
Fatigue loading
Energy dissipation
Failure analysis
Angle shear connector
Push-out test

ABSTRACT

To inspect the fatigue energy dissipation of angle shear connectors under fully reversed cyclic fatigue loading while embedded in a high strength concrete (HSC) slab, a series of experimental push-out tests was conducted. The experimental tests comprised eight push-out test specimens with different geometries of angle connector. The failure of the angle connector under monotonic and low cyclic fatigue loading was tested and the observations were discussed. The results show that the ductility performance for angle shear connectors embedded in HSC was inadequate. However, reasonable strength resistance under monotonic loading and a small amount of fatigue energy dissipation under cyclic fatigue loading for connector was detected. All push-out test specimens experienced connector fracture failure with very low energy dissipation when subjected to fatigue loading. Details of the failure analysis and fatigue energy dissipation of the angles in HSC are fully described in the results.

1. Introduction

A shear connector is the part that guarantees the shear exchange between the steel profile and the concrete slab in a composite construction [1]. The most normally utilized sorts of shear connectors as a part of steel–concrete composite beams are headed shear studs and Perfobond shear connectors [2,3]. However, when it comes to composite beams, C-shaped shear connectors, for instance channels and angles, have become increasingly more common over the last decade.

Because of the restrictions in the execution of headed studs and Perfobond shear connectors, the utilization of C-shaped shear connectors as an alternative to the normally utilized sorts of shear connector has been proposed. Such restrictions include a number of constraints in the fatigue behaviour of studs. As a case in point, because of the welds and the need to have specific welding equipment with high power generation on site, and the occurrence of fatigue cracks under cyclic fatigue loading [3–5]. The issue with Perfobond shear connectors is the trouble in positioning the section for the slab for lower reinforcement as the steel bars have to cross the connector openings [6] which requires the drilling of holes. Hence, production takes a longer time and requires higher cost.

In addition, assembling of the C-shaped shear connectors is simpler compared to alternate connectors, since, in most steel shops, standard sizes for hot rolled steel profiles of C-shaped shear connectors are available. In addition, their production is very easy and simple, and, by simple cutting of the long steel profiles, these sorts of connector can be effortlessly produced.

* Corresponding author. Tel.: +60 17 243 4142.
E-mail addresses: shariati@siswa.um.edu.my, shariatimehdi@yahoo.com (M. Shariati).

http://dx.doi.org/10.1016/j.engfailanal.2014.02.017
1350-6307/

In comparison to the headed stud and Perfobond connectors, the assembly cost and time for producing C-shaped connectors are fundamentally lower.

With regard to the load carrying capacity, C-shaped connectors show higher capacity, and, with the utilization of a conventional reliable welding system, they could be welded effortlessly to steel beams [6]. While stud connectors may require a few inspections (e.g. bending test), this is not required for C-shaped connectors. Similarly, the utilization of C-shaped connectors eases the positioning of the slab for lower reinforcement which is recognized as a problem in the application of Profobond connectors [5,7]. The restrictions and trouble encountered when utilizing the headed studs and Profobond shear connectors in composite beams could be overcome with the utilization of C-shaped connectors.

As previously mentioned, the C-shaped shear connectors might be easily produced with angle and channel profiles. The angle connectors, compared to the channel connectors, could be less expensive and more practical because of the lack of one flange compared to the channel connector, which, ultimately, saves more steel. Fig. 1 shows this type of shear connector.

To date, there have been various studies concerning the performance of angle connectors. Rao [8] depicted the essential outcomes of the push-out tests directed on specimens with some types of shear connector including the angle shear connectors. Their outcomes demonstrated that C-shaped shear connectors, including angle connectors, showed significant adaptability and greater load carrying capacity compared to different sorts of shear connector.

The ultimate strength and deformation of different types of shear connector in composite members, including angles, channels, and T-shaped shear connectors were also examined in a study conducted by Hiroshi and Kiyomiya [9]. It was concluded that in the push-out test, the mode of failure of the samples was greatly affected by the strength of concrete, the shape of the shear connectors and the direction of the shear connectors.

Choi et al. [10,11] investigated the fatigue strength of the welded joints between the bottom plate and the angle shear connectors in steel–concrete composite slabs through fatigue tests and finite element analysis. Based on their results, it was verified that at the welded joint, the stress level was low and significantly less than the fatigue limit.

Fukuzawa et al. [12] carried out a wheel trucking test on composite slabs made with the angle shear connectors. The study was conducted to determine the applicability of the angle connectors in continuous composite steel girders and their performance under moving load conditions. The outcome of the research indicated that the composite slabs exhibited sufficient stiffness and fatigue durability.

In another study, Saidi et al. [13] studied the relationship between the transferred shear force and the relative displacement of T-shaped and angle shear connectors used in a steel-concrete sandwich beam and presented a numerical model.

In order to investigate the shear load-slip relationship of angle shear connectors, Ros and Shima [14] recommended a new test set up, through which they concluded that the shear capacity of the shear connector was influenced by the direction of the shear force on the connector.

In other research by Shariati et al. [15,16], the behaviour of angle shear connectors in composite beams under monotonic and fully reversed cyclic fatigue loading was investigated. The study discussed the fracture type of failure, strength degradation, the ultimate shear capacity and the ductility criteria of the angle shear connectors under monotonic and cyclic fatigue loading when embedded in a reinforced normal strength concrete slab. In continuation of that research, another study by Shariati et al. [17] was conducted for comparison of the behaviour between the channel and the angle shear connectors under monotonic and fully reversed cyclic fatigue loading. The former research aimed to compare the connection shear resistance, ductility and failure modes of channel and angle shear connectors to check the efficiency of both types of connector.

The application of high strength concrete (HSC) has become a common development in modern construction. Using this type of concrete produces more slender structures, increases their load carrying capacity, changes the ratio between the maximum slip requirement and connection deformation capacity and requires direct connection ductility checking [18]. In addition, it produces more cost-effective products and offers a feasible technical solution or a combination of both. Meanwhile, it should be noted that the application of HSC could be limited due to its low ductility. For composite beams made of HSC, the ductility behaviour and load carrying capacities are of particular interest as well as the fatigue behaviour.

The use of HSC along with common types of shear connector in composite beams has widely increased over the past few years. However, as concluded from the literature, the angle shear connector could be of efficient use in composite beams. The

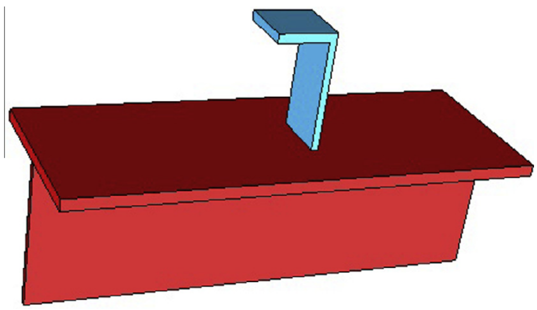

Fig. 1. Typical angle shear connectors.