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Predicting pull-out behaviour based on the bond mechanism of arch-type steel fibre in cementitious composite

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ABSTRACT

In this study, we investigated the bond mechanism associated with the pull-out behaviour of arch-type steel fibre in cementitious composite. Prediction model development and bond mechanism analysis were conducted in parallel on hooked-end-type steel fibre having the same tensile strength. Pull-out tests were performed using the single fibre-single-sided method, according to JCI SF-8. The bond mechanism analysis of arch-type steel fibre, from the pull-out test results using a transparent epoxy matrix, confirmed that pull-out resistance was maintained, without a drastic decrease in the pull-out load under plastic bending or frictional forces; these forces acted simultaneously throughout all pull-out stages until completion. Based on our results, the pull-out behaviour of arch-type steel fibre was classified into three pull-out stages: debonding and pull-out initiation, achievement of maximum pull-out load while passing through the bend section, and the final pull-out stage as the fibre passed through the arch. The proposed model for the pull-out behaviour of arch-type steel fibre was verified by a pull-out test using a cement matrix. The maximum pull-out resistance strength and interfacial toughness differed by 2.0% and 17.0%, respectively, from values given by the prediction model, and coincided with three-stage pull-out behaviour.

1. Introduction

Over the past 40 years, there have been significant advances in the use of various reinforcement materials, such as steel fibre, to address the brittleness of cementitious composites [1–7]. In the composite, the steel fibre is dispersed randomly throughout a three-dimensional matrix [7–9]. The dispersed fibre plays an important role in controlling the generation and growth of cracks. Additionally, steel fibre reinforcement improves ductile behaviour by enhancing the energy absorption capability of the cementitious composite [1–9].

On a cracked surface, the bridge effect of steel fibre is closely correlated with its pull-out mechanism. The degree of bridging by steel fibre in cementitious composite can be determined by pull-out tests [10–12]. Numerous studies have been carried out on the pull-out behaviour of straight-type steel fibre [13,14], as well as the bond performance of steel fibre under mechanical deformation [15–18].

Laranjeira et al. [17] developed a model to predict the pull-out behaviour of hooked-end-type steel fibre, based on the embedded angle; the model was verified by test data. Fig. 1(a) shows the pull-out load–slip diagram of hooked-end-type steel fibre from their study [17]; eight points along the curve were chosen to derive the equations describing the pull-out mechanism. Fig. 1(b) shows a schematic representation of eight key points in the curve, which corresponded to eight stages in the pull-out process.

Zile et al. [16] proposed a mathematical model for the pull-out load stage of hooked-end-type and crimped-type steel fibre, based on pull-out load–displacement data (Fig. 2); five pull-out stages were identified in terms of the associated plastic bending and frictional forces, as given by Eq. (1) [16]:

$$P=\begin{cases} T_2+2\tau\pi r(H_s+l+l_e-\Delta), & \Delta\leqslant l_e \\ T_2+\frac{T_1-T_2}{\rho\theta}(\Delta-l_e)+2\tau\pi r(H_s+l), & l_e<\Delta\leqslant l_e+\rho\theta \\ T_1+2\tau\pi r(H_s+l+l_e+\rho\theta-\Delta), & l_e+\rho\theta<\Delta\leqslant l_e+l+\rho\theta \\ T_1(2-\frac{\Delta-l_e-l}{\rho\theta})+2\tau\pi r(H_s), & l_e+l+\rho\theta<\Delta\leqslant l_e+l+2\rho\theta \\ 2\tau\pi r(H_s+l+l_e+2\rho\theta-\Delta), & l_e+l+2\rho\theta<\Delta\leqslant l_e+l+2\rho\theta+H_s \end{cases} \quad (1)$$

where H_s is the length of the embedded part of the fibre without the hook before pull-out.

In this study, we investigated the bond mechanism associated with the pull-out behaviour of arch-type steel fibre in

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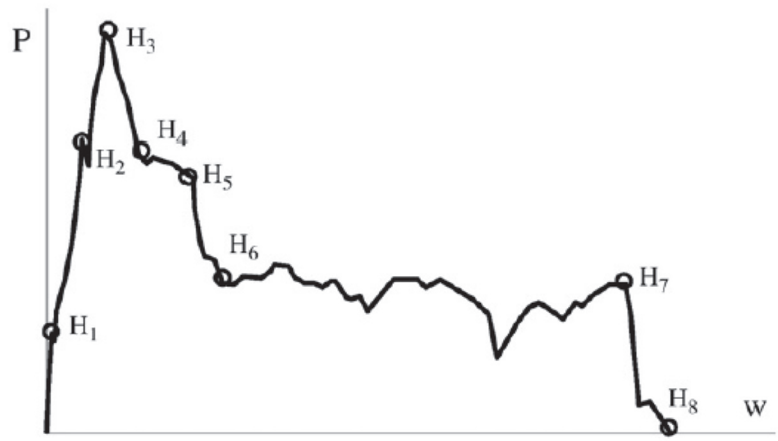
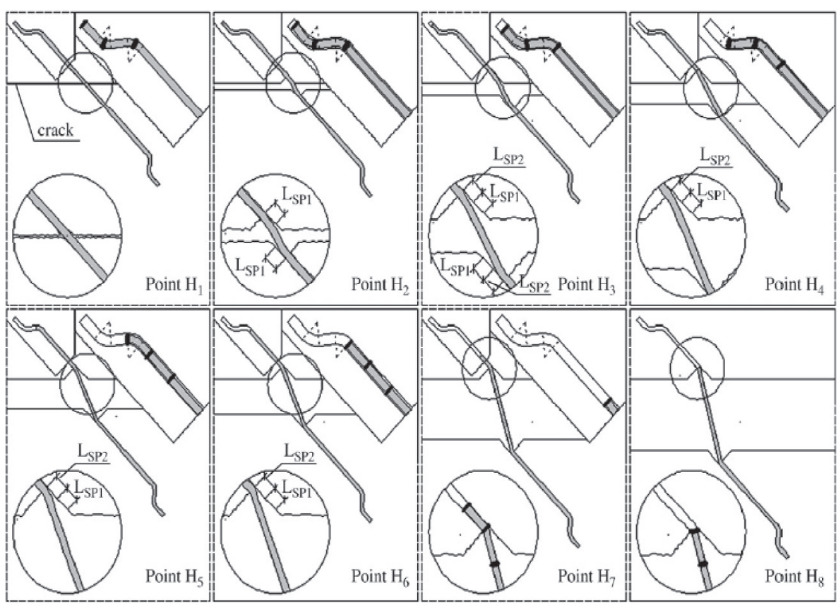
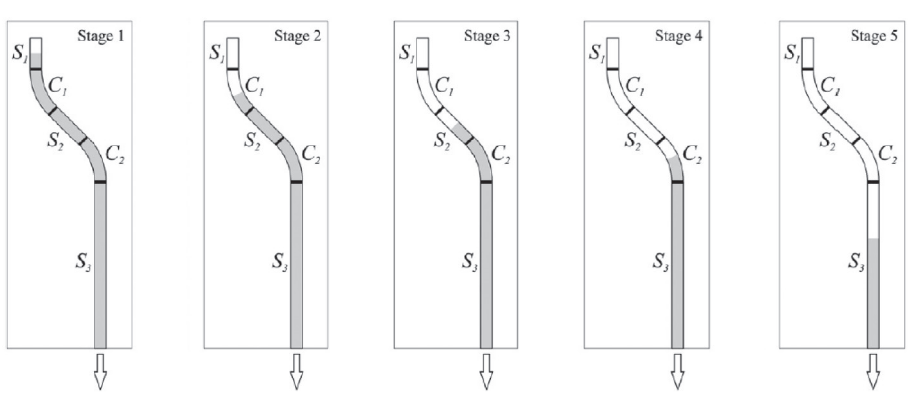


(a) Pull-out load-slip diagram



(b) Main stages of the pull-out process

Fig. 1. Schematic diagram of the pull-out model for inclined fibres with hooked ends [17].



(a) Stage 1 (b) Stage 2 (c) Stage 3 (d) Stage 4 (e) Stage 5

Fig. 2. Schematic diagram of hooked-end-type fibre pull-out behaviour [16].