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A new method for pull out test of reinforcing bars in plain and fibre reinforced concrete

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ABSTRACT

The bond of reinforcing bars in concrete is crucial in anchorage of reinforcing bars and crack control of reinforced concrete. It is generally measured by pull out test of a reinforcing bar embedded in a concrete block. However, the different test methods yield different test results. In this research, finite element analysis was carried out to reveal the variations in stress distribution inside the concrete block due to uneven contact pressure and friction at the concrete block-steel platen interface of the test setup. To minimize the test errors due to such uneven contact pressure and friction, the test setup was redesigned by inserting a rubber pad and a PTFE film at the interface. Using the redesigned setup, pull out tests of reinforcing bars in plain and fibre reinforced concrete were conducted and the results compared to those obtained without rubber pad or PTFE film installed. It was found that the new test would yield lower and less variable bond strength and stiffness results. This improved test method would provide more accurate bond properties for structural analysis and design.

1. Introduction

In reinforced concrete, effective bond between reinforcing bars and concrete is vital for full development of composite action. Hence, the bond of reinforcing bars plays an important role in the structural behaviour of reinforced concrete [1]. Inadequate bond could lead to excessive bond-slip of the reinforcing bars, thus causing ineffective anchorage of the reinforcing bars and serious cracking of the reinforced concrete [2]. On the other hand, the addition of fibres could improve the bond of reinforcing bars and thus enhance the bearing capacity and certain other performance attributes of the reinforced concrete [3].

In general, the bond of reinforcing bars in concrete is particularly important in regions subjected to stress concentration, shear and contraflexure, such as bearings transmitting concentrated loads, beam-column joints in buildings and narrow stitches in bridges [4–7]. Hence, it is necessary to take into account the bond strength of the reinforcing bars during ultimate strength design. The bond of reinforcing bars is also important in crack control during serviceability and durability design. Firstly, the crack width is associated with the bond-slip of the reinforcing bars at individual cracks because it is actually equal to the sum of the bond-slip at the two sides of the crack [8]. Secondly, the crack formation process could be delayed or even altered by improving the bond between the reinforcing bars and the concrete so as to avoid cracking or at least to reduce the extent of cracking [9].

In recent years, the addition of various kinds of fibres to transform the concrete from plain concrete to fibre reinforced concrete (FRC) has emerged to become an effective method of improving the bond of reinforcing bars [3,10,11]. In fact, apart from achieving better bond between the reinforcing bars and the concrete and better crack control of the reinforced concrete, FRC is proven to be effective in improving the strength, ductility and other mechanical properties of concrete [12] and enhancing the shock vibration resistance and earthquake resistance of concrete structures [13,14]. It is gaining popularity in some applications.

For studying the effects of the bond strength and bond-slip, representative and accurate testing of the bond characteristics of reinforcing bars in plain and fibre reinforced concrete is necessary. However, this is not at all easy because the bond strength and failure mode are dependent on the stress conditions at the reinforcing bar-concrete interface [15], which in turn are influenced by the details of the test setup. The pull out test of pulling a reinforcing bar out of a concrete block is the most commonly used test method to measure the bond strength between reinforcing bars and concrete [16–18]. However, up to now, there exists no standardized and generally accepted test method, and different researchers are using different versions of pull out test with different test setup developed independently. Consequently, the test results obtained by different researchers are not consistent, thus rendering the test results not directly comparable and very difficult to interpret.

One main hurdle associated with the existing test methods is that the stress conditions at the reinforcing bar-concrete interface are quite

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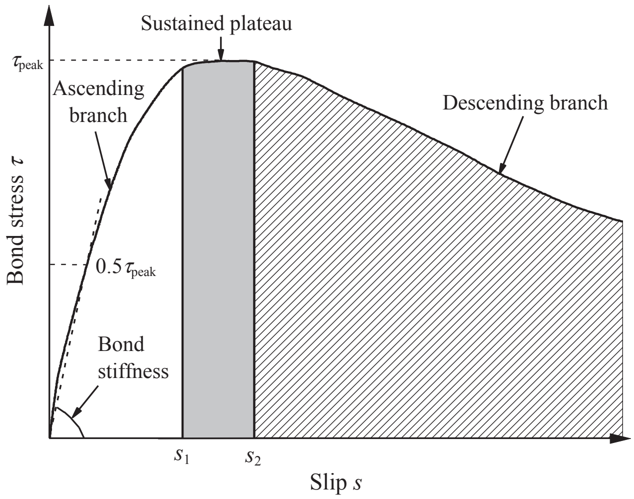

Fig. 1. Typical bond stress-slip curve.

sensitive to the boundary conditions at the concrete block-steel platen interface in the test setup. Non-uniform contact pressure and friction at the concrete block-steel platen interface have certain effects on the stresses developed at the reinforcing bar-concrete interface and thus might affect the pull out test results. To overcome this hurdle, in this research, the test setup was redesigned to develop a new test method by inserting a composite layer of soft rubber pad and low friction polytetrafluoroethylene (PTFE) film at the concrete block-steel platen interface. The new test method was applied to measure the bond properties of reinforcing bars in plain and fibre reinforced concrete and the test results were analysed to evaluate the performance of the new test method.

2. General bond behaviour

The bond between the reinforcing bar and concrete comprises of chemical adhesion, friction and mechanical interlocking action [19]. These three components of bond could vary with the strength of concrete, characteristics and amount of fibres in the case of FRC, rib geometry of reinforcing bar, bleeding and casting direction of concrete, and confining stress at reinforcing bar-concrete interface. Fig. 1 shows a typical bond stress-slip curve. The actual curve tends to fluctuate due to intrinsic variations of material properties and jerky formation and propagation of micro-cracks in the surrounding concrete. Hence, it should be regarded as a statistical mean curve for general design applications. According to the Model Code MC 2010 [1], there are three branches in the curve: (i) an ascending branch with a high initial bond stiffness and a gradually decreasing bond stiffness due to break down of chemical adhesion and micro-cracking of surrounding concrete; (ii) a sustained plateau with nearly constant bond stress arising from the plasticity provided by confinement if the surrounding concrete is well confined; and (iii) a descending branch, where the bond stress decreases due to bond failure by either bar slipping or concrete splitting.

3. Existing test methods

Throughout the years, several different versions of pull out test have been developed [3,15,20–30]. They all have the common features that the reinforcing bar is cast inside a concrete block, the reinforcing bar is pulled out by applying a tension load to the reinforcing bar, and the concrete block is restrained from movement by a steel platen acting against the tension load. However, the other details of the test setup vary from one test method to another, as summarized in Table 1. As can be seen from the table, the differences in test setup are mainly in two aspects, namely: making of test specimen and application of loading.

Regarding the making of test specimens, the reinforcing bar is cast in the concrete block in some test methods in a vertical position and in some other test methods in a horizontal position, as depicted in the second column of Table 1. Moreover, the reinforcing bar is bonded to the concrete block at the centre of the concrete block in some test methods but near or away from the bearing surface (the concrete block-steel platen interface) or throughout the whole length of embedment in some other test methods, as depicted in the third column of Table 1. Lastly, the bearing surface can be a moulded surface in some test methods or a trowelled surface in some other test methods, as depicted in the fourth column of Table 1. These differences, albeit apparently minor, may have certain effects on the test results because (i) the casting position of the reinforcing bar would affect the quality of interfacial zone at the surface of the reinforcing bar, (ii) the bonding of the reinforcing bar to the concrete block near the bearing surface could cause spalling failure of the concrete, and (iii) the roughness of the trowelled surface would cause uneven contact pressure distribution at the concrete block-steel platen interface.

Regarding the application of loading, the action is applied to the reinforcing bar and the reaction is provided to the concrete block by a steel platen restraining the movement of the concrete block. The contact pressure at the concrete block-steel platen interface could be quite irregular due to imperfect flatness of the concrete and steel surfaces there. To minimize irregularity of the contact pressure, in some test methods, a soft rubber pad is inserted at the concrete block-steel platen interface, but somehow in some other test methods, no soft rubber pad is provided, as depicted in the fifth column of Table 1. Moreover, friction could be developed at the concrete block-steel platen interface due to lateral expansive movement of the concrete there and restraint of

Table 1
Test setups of existing pull out tests.

Reference of test method	Making of test specimen		Conditions at concrete block-steel platen interface		
	Casting direction	Bonded portion	Moulded/trowelled surface	Soft rubber pad	Friction reduction layer
Huang et al. [3]	Rebar horizontal	Centre portion	Moulded	No	None
Eligehausen et al. [15]	Rebar horizontal	Centre portion	Moulded	No	PTFE
Harajli et al. [20]	Rebar horizontal	Centre portion	Moulded	Yes	Grease
Yalciner et al. [21]	Rebar horizontal	Centre portion	Moulded	No	None
Guneyisi et al. [22]	Rebar vertical and upwards	Whole length	Trowelled	No	None
Yoo et al. [24]	Rebar vertical and upwards	Centre portion	Trowelled	Yes	None
Ganesan et al. [25]	Rebar vertical and upwards	Whole length	Trowelled	No	None
Castel and Foster [26]	Not reported	1/2 length near bearing surface	Not reported	No	None
Shen et al. [27]	Not reported	1/2 length away from bearing surface	Not reported	No	None
Wu et al. [28]	Rebar vertical and upwards	1/5 length near bearing surface	Trowelled	No	None
Yang et al. [29]	Not reported	Centre portion	Not reported	No	None
Garcia-Taengua et al. [30]	Not reported	Away from bearing surface	Not reported	No	None

Note: Rebar means reinforcing bar.