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Bond characteristics of near surface mounted CFRP bars

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HIGHLIGHTS

- ▶ This paper investigates bond behaviour between concrete and NSM CFRP bars.
- ▶ Effects of bond length, groove size, bar shape, etc. have been investigated.
- ▶ Critical failure modes have been identified depending on bar shape and bond length.
- ▶ CCSF is the critical failure mode for NSM CFRP bars with high area/perimeter ratios.

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ABSTRACT

Near Surface Mounted (NSM) strengthening is an emerging retrofit technique, which involves bonding fibre reinforced polymer (FRP) reinforcement into grooves cut into the surface of a concrete member to be strengthened. This technique offers many advantages over external bonding of FRP reinforcement, for example, an increased bond capacity and protection from external damage. To date, significant research has been conducted into the NSM FRP strengthening technique. However, there are still some areas which need further research in order to fully characterise bond and anchorage of these bars. The particular objectives of this research were: to investigate bond behaviour of NSM FRP bars, to understand the critical failure modes involved, and to predict bond strength and anchorage length requirements. Several significant variables affecting bond, such as bond length, bar shape and groove dimensions have been considered, and the results are presented and discussed in this paper. It is seen that for both circular and square bars with relatively high cross-sectional area/perimeter ratios, concrete cover separation failure is the upper-bound failure mode which limits the load capacity when the other influencing parameters, such as bond length, resin cover thickness and concrete strength, are optimised. For rectangular bars, tensile rupture of the FRP is seen to be a limiting condition.

1. Introduction

The Near Surface Mounted (NSM) fibre reinforced polymer (FRP) strengthening technique involves bonding FRP bars into grooves cut into the concrete cover of a structural member to be strengthened. The technique offers many advantages over external bonding of FRP reinforcement, for instance, increased bond capacity, due to a larger bonded surface area, and protection from external damage due to external impacts, since the bar is embedded within the concrete cover. Previous research indicates that the NSM technique is an effective technique for increasing both flexural and shear capacities of structural members [1–4].

Although near surface mounting of FRP bars is a relatively new technique, the first practical use of near surface mounted steel bars was reported in the late 1940s [5]. The steel bars were mounted and grouted into the concrete cover of a bridge deck in Sweden as a remedial action for the settlement of negative moment reinforcement which occurred before the concrete hardened. The first NSM application using FRP reinforcement was reported in 1998 which involved strengthening of Pier 12 of the Naval Station San Diego, CA (USA) (Warren, 1998 cited by [6]), where NSM CFRP rods were used to increase the capacity of the deck slab in the negative moment regions.

Bond is the key parameter which ensures composite action between the FRP reinforcement and concrete. The success of a strengthening system is highly dependent on the interfacial bond properties between the reinforcement and the concrete which, in turn, depends upon a number of parameters. Therefore, it is of prime importance to critically investigate the bond properties of NSM FRP bars so that the technique can be adopted with confidence. To date, several research studies found in the literature have considered various bond parameters such as bond length, surface

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texture of the FRP bar, type of FRP material, groove dimensions and adhesive type [6–12]. However, the existing models are based on limited test data and are specimen dependent. Therefore a generalised model of behaviour, which takes the many possible failure mechanisms into account, is required.

As indicated above, whilst NSM strengthening is an attractive method for rehabilitating concrete structures, there is comparatively little research which has been undertaken to aid understanding of anchorage failure mechanisms. Compared to surface mounted FRP strengthening systems, there are many more parameters which can be varied or chosen in an NSM design and each parameter influences the bond characteristics and failure modes. At present design guidance for NSM relies largely upon empirical models of behaviour which do not adequately capture the mechanics of the behaviour and are limited in the extent of applicability to those parameters on which the models are based. It is only through thoroughly investigating the different possible modes of failure and the influencing parameters that it is possible to give comprehensive, rational and generalised design guidance which will lead to economic and safe design solutions. The particular objectives of the research presented in this paper are to investigate bond behaviour of various shapes of NSM FRP bars, and to identify the critical failure modes and their underlying mechanics which will allow the development of analytical models which can predict bond strength and anchorage length requirements.

2. Experimental investigation

2.1. Specimen configuration

In order to investigate the anchorage behaviour of NSM reinforcement and identify how the parameters involved influence the mechanisms of failure, a series of beam pull-off tests were carried out. The specimen dimensions and reinforcement details are shown in Fig. 1. The specimen configuration was chosen to represent the free body diagram of the shear span of a beam test loaded under four-point bending. The bond tests can therefore be classified as beam tests as far as the free body diagram is concerned. Such beam-type bond tests are more representative of actual stress fields in beams, compared to direct pull-out tests, as the concrete surrounding the reinforcement is subjected to tension. They can be used not only for the determination of bond strength but also for identifying crack widths and crack spacing [13].

The bond specimens were of 220 mm $\times$ 110 mm in cross-section and 750 mm long. This is an easily manageable size and, since the specimens were tested vertically, it was possible to visually inspect the bonded joint as loading progressed. Further, the specimen configuration allowed monitoring of both the loaded-end and free-end slips. The specimen contained internal longitudinal steel reinforcement and shear links. The inclusion of steel reinforcement is representative of the real situation of strengthening a beam with NSM FRP reinforcement. Some previous studies [6,11] omitted this internal steel and it was therefore expected that these bond tests might exhibit different behaviour to that found in the literature.

2.2. Test matrix

Carbon FRP bars were selected for the investigation due to its superior properties (compared to aramid and glass) and widespread use in retrofitting applications. The experimental program consisted of 11 series of tests, each composed of four bond specimens, designed to investigate the effect of the following parameters on the bond between NSM CFRP bars and concrete:

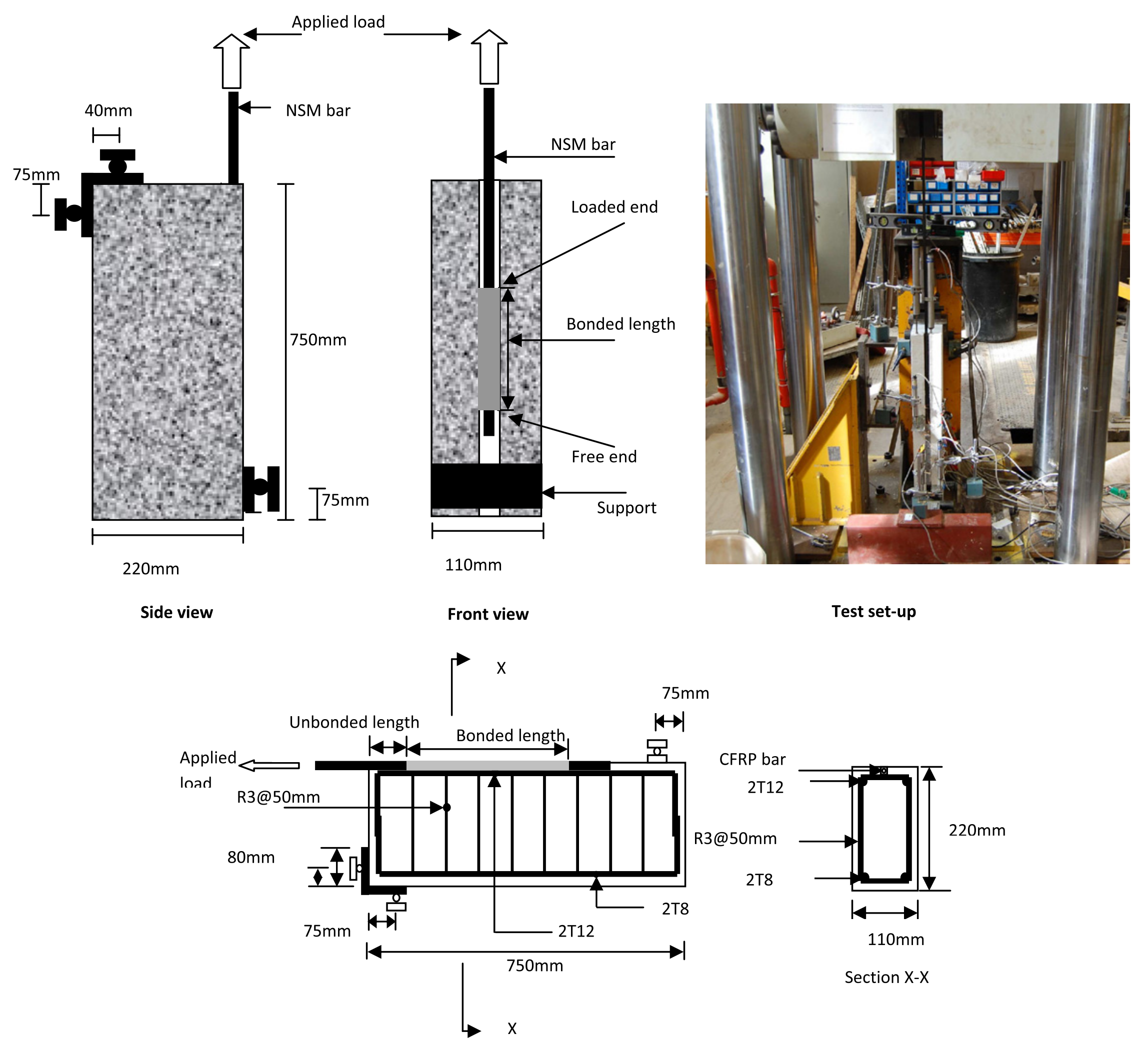

Fig. 1. Specimen and reinforcement details.